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The Greatest Service

WITH the publication of this editorial, the PGMIL TRANSACTIONS is announcing a new publication program that is unique among the IRE Professional Group TRANSACTIONS. All previous issues of this journal have been limited to papers obtained either by invitation or by selection from papers obtained through direct contact with potential authors. This has been neither by intent nor design, but was forced by a lack of appropriate contributions received by your editor. It is only natural that an author would prefer to publish in a journal that commands the attention of the majority of those working in his field of specialization rather than a journal in a field so broad as to encompass the technical areas of most of the other 27 IRE Professional Groups. As a result, the editorial policy in the four-year history of this journal has been one of experimentation, the objective being to develop ideas and to obtain experience on which to build a sound publication program. The broad outlines of such a program are now clearly evident. But before presenting here the philosophy of the new publication program, it is appropriate that we review briefly the past four years in order to understand the background that led to the adoption of the new program.

In the first year, 1957, two issues were published, one in March and one in December. The papers in both issues were obtained individually upon personal invitation by the editors. It was felt that the publicity provided by the appearance of the first two issues would attract good, original contributions for succeeding issues and that it would no longer be necessary to depend upon invited papers. Such was not the case. Very few papers were received, none of which were acceptable for publication. When it finally became evident that the PGMIL TRANSACTIONS could not perform its greatest service under the conventional editorial policies of the other Professional Groups, the decision was made to embark upon a series of special issues coordinated through a guest editor chosen for each issue. This proved to be a most fortunate decision, for it provided a wealth of editorial assistance in addition to the depth of technical knowledge and judgment that could only be brought to bear by men of wide experience in their respective fields of endeavor. The first of the special issues appeared in December, 1958, on "Space Technology" under the guest editorship of Harry Davis. Beginning with the January, 1959, issue on "Systems Engineering" under Dr. G. E. Valley, Jr., the journal was established as a regularly scheduled quarterly. The next two issues were on "Electronic Propulsion" under Krafft A. Ehricke, and "Electronic Simulation" under Capt. E. C. Callahan. In October, 1959, a second tack was taken with the initiation of three service issues on the Air Force, Navy, and Army space programs under the guest editorships of General B. A. Schriever, Capt. R. Bennett, and Dr. H. K. Ziegler, respectively. Finally, a third type of activity was undertaken in October, 1960, with a special issue commemorating the 100th anniversary of the Signal Corps under the guest editorship of Col. H. McD. Brown.

In view of the success achieved in the program to date, two general conclusions seem inescapable. The PGMIL TRANSACTIONS can perform its greatest service by integrating the technical specialities of the other Professional Groups as they apply to the needs of the military services, and by doing so under the guest editorship of those most capable of providing the leadership required. Therefore the major portion of the publication program henceforth will be in the form of special issues designed to bring together the technical achievements of one field or by one group of workers. Each issue will be open to contributions from anyone working in the area covered by that issue. In order to encourage authors to contribute papers to the PGMIL TRANSACTIONS, the forthcoming publication schedule will be announced regularly in advance on the inside back cover, including the topics and the guest editors to whom manuscripts should be sent for review, beginning with this issue. Your editor earnestly invites suggestions from the membership on topics for future issues. It is only through your continuing support that the PGMIL TRANSACTIONS can grow in its ability to meet the needs of the membership.

DONALD R. RHODES, *Editor*

The Breakthrough of the "Scharnhorst"—Some Radio-Technical Details*

CAPTAIN HELMUTH GIESSLER†

This is a sequel to the paper by Sir Robert Watson-Watt that appeared in these TRANSACTIONS in March, 1957. In response to an invitation from the Editor, Captain Giessler describes the historic escape of the German battleships *Scharnhorst*, *Gneisenau*, and *Prinz Eugen* through the British radar fence along the English Channel in World War II.—*The Editor*

IN 1957, Sir Robert Watson-Watt published a noteworthy article[1] in which he presented a critical review of the successful breakthrough of the German fleet in February, 1942. From the British standpoint he could call attention to a number of technical and operational experiences and mistakes. This is natural and understandable when such a unique operation is observed from various points of view. It might, therefore, be of interest to American readers to learn from the German side some of the technical details and modes of operation, particularly those concerning radio-technical problems. The author was a member of the staff of Vice-Admiral Ciliax, the Commander, as navigation officer of the battleship *Scharnhorst*, and therefore influenced the preparations from the very first. In addition to the war diary of the *Scharnhorst*, reports of the jamming stations were available as the basis for this paper.

The problems and objectives of the German command shall be outlined briefly. At the beginning of January, 1942, the officer in charge of the task force lying at Brest received the order to prepare for a transfer of the ships to Norway. The battleships *Scharnhorst* and *Gneisenau* had been lying in at Brest since the end of March, 1941, *Prinz Eugen* since May. The British Air Force had tried through continuous air attacks to put the ships out of commission. However, they could achieve only a few hits. By the end of 1941, the repair work was nearly completed.

Operation of these ships in the Atlantic could no longer be considered, due to the substantially strengthened defense of the British fleet and due to the official entry of the United States into the war at the end of 1941. For this reason, the valuable and combat-ready ships were supposed to go out from the Norwegian fjords to disturb or even disrupt the convoys destined for Russia. In particular, they were supposed to induce increased defense measures of the Allied fleet by their very presence as a fleet. Contrary to the opinion of Grand Admiral Raeder, the Supreme Commander of the Navy, Adolf Hitler, as Supreme Commander of the Wehrmacht, decided that the ships would be transferred through the Channel, at first into the North Sea, and from there to Norway. In the decisive meeting, Hitler very correctly deduced that, in case of successful surprise, any retaliation by the British Navy and Air Force would come too late to impair the success of the operation.

For a successful result the following conditions had to be realized:

1) The preparations had to occur so that the strictest secrecy was assured. On the ships, only those officers who were absolutely necessary were to be initiated into the actual task. This decisive provision could be fulfilled in spite of considerable activity by allied espionage, thanks to a well-thought-through camouflage and concealment program.

2) Only the most necessary trial runs were made in the estuary at Brest. These trial runs, which were necessary after making needed repairs on engines and boilers, were also needed for practice and for the training of the crew. Never before was a task force able to acquire combat readiness, after such a long idleness, with so few practice runs. This was possible only because a part of the crew on board in March, 1941, were again ordered on board. These men had an extensive war experience, and could thus be put to use immediately.

3) Throughout the entire duration of the operation, the group had to be protected by a strong and continuing fighter escort. The operational readiness of this fighter escort was developed during the few trial runs.

4) The weather conditions in the Channel had to be favorable for the carrying out of the operation. If too good, the weather would aid the British. Yet it had to be fair enough for German aircraft to operate.

After the Supreme Commander had issued the final order, there remained only four weeks for the preparation and concentration of the escort ships and the fighter units. This short time was used well. The way cleared by the mine sweepers through the Channel led mostly over deep water, so that the ships could proceed at a high speed. There were, at that time, only limited electronic navigational aids. It was decided that ordinary radio beacons should be used. As they were op-

* Received by the PGMIL, April 19, 1959.

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[1] Sir R. Watson-Watt, "Battle scars of military electronics—the *Scharnhorst* break-through," IRE TRANS. ON MILITARY ELECTRONICS, vol. MIL-1, pp. 19–25; March, 1957.

erated by French personnel, the true task could not be revealed. The radio beacons were ordered and switched on in the usual way. It was later discovered that many of these radio beacons had faulty transmitters or other shortcomings, so that direction-finding simply was not possible. Moreover, small mine sweepers at well-marked points of the track were stationed as an aid to dead reckoning, because the track itself could not be shown by marked buoys or similar devices. Thus, through their positions, these mine sweepers had to operate as living buoys so to speak. In addition, it should be mentioned that navigation charts and tide tables for the operation were specially calculated, and were, therefore, very valuable resources.

The time schedule for the operation would, against all expectations, be determined by the Commander in Chief in the following manner: Put to sea from Brest in the evening, pass the narrows of Dover-Calais by noon of the following day, navigate further along the Dutch coast in the afternoon; and enter the North Sea in the evening. A 28-knot cruising speed was considered.

Naturally the fighter escort was also included in this carefully worked out operation. The command of this air protection, consisting of day and night fighter planes, was transferred to the "General of the Fighters," General Galland. It should be mentioned here that the German Navy unfortunately did not have at its disposal its own flying units; rather, these had to be requisitioned from the Luftwaffe. On the whole, these demands of the Navy were fulfilled only unwillingly and with reluctance. But in this operation, everything went smoothly; the cooperation was without friction. The Luftwaffe did not have enough units for this task, due to the great demands in Russia. The problem, therefore, was to have the greatest possible number of airplanes at all times at the disposal of the group. According to the view of Galland, the success of the attacking forces depended on how long the British would need in order to mobilize the RAF against the surprise appearance of our naval force. Galland, at this time, was correct in this appraisal to the fullest extent!

For the carrying out of smooth cooperation, the Luftwaffe sent liaison staffs to the Navy. On the *Scharnhorst*, the flagship of Vice Admiral Ciliax, the "Fighter Controller Board" embarked with a few members of his staff. On the *Gneisenau* and *Prinz Eugen*, there were fighter controllers.

From the ship the fighter planes could immediately be directed by means of radio telephone. Furthermore, the frequencies of the air warning service were tied in with the command radio circuit of the fighter units. Thereby the ships were immediately instructed concerning air situations and the orders for action to the fighter pilots. These additional frequencies could be tied in, thanks to the excellent radio equipment of the ships, additional to the very extensive radio circuit of the Navy, including the frequencies of the escort ships. During the trial runs, this extensive communication apparatus could be tried and well coordinated. The responsible officers had to invent fanciful exercise conditions in order to carry out a somewhat credible war game, which could not be discerned from the real purpose of the task by clever people.

The preparations of the Luftwaffe were naturally extraordinarily extensive. After the time schedule was determined, the preparations for the flying units and the command posts could be determined. Since the fighter escort of the task force was supposed to be established from the first dawn of morning until the full darkness of evening, the first airplanes had to meet the ships somewhere in the Seine Bay and accompany them to the North Sea. Accordingly, the Western Central Command was established in Le Toquet; the night and day fighter planes lay in the area of Abbeville-Lille-Calais. At 1500 hours on this so called "X Day," the control center in Schipol and the airbases in the area of the mouth of the Rhine and Scheldt had to be ready. By evening the airplanes were supposed to join bases in the area of Jever-Wilhelmshaven; the central command was located at Jever.

It was particularly important that the communications systems—that is, radio, telephone, and teletype communications—be established as well as possible between the command centers, on the one hand, and the airports, on the other. The chief, the general of the fighter-pilots, personally directed the fighter units from the individual command centers; he took charge of reserves and their transfer in the next area. An immense profusion of tasks had to be accomplished in an unusually short time. Of course, additional radar equipment was installed by the Luftwaffe, which was to inform the command about the military situation in the air and to direct the pilots to their goals. The radio contact between the flagship on which the "Fighter Controller Board" was stationed and the command centers on land was achieved via very high frequency (VHF) radio telephone, or by means of long waves and coded messages. Needless to say, the ships had to observe strict radio blackout until the task force was located with certainty.

For the fighter escort, three fighter groups were available with a total of 250 fighters and 30 night-fighters. These airplanes were divided up according to intended combat plans. Due to the forementioned difficult conditions, no reserve planes were on hand. Therefore, the operations orders provided that the airplanes should remain with the ships as long as their fuel reserves permitted. They should then fly to the next air field where they would quickly be retanked and supplied with new ammunition. These airplanes would first remain in readiness until new combat orders were received.

All these preparations could be carried out undisturbed. Naturally, complete secrecy was not always possible, but the task could always be concealed from the German soldiers, as well as from the French people. The

English were acquainted with the preparations; they correctly interpreted the time period of the operation, but they made a decisive mistake in assuming that we would pass by the Narrows of Dover-Calais at night.

Finally, only the day most suitable for the breakthrough had to be determined. Many circumstances had to be considered. From the beginning of February, the extensive preparations were completed to a large degree. Darkness then prevailed from 2030 hours until 0830 hours. (*Note:* France reckoned at that time by Middle European time, which is Middle Greenwich time plus one hour.) The new moon was on the 15th of February. The most favorable tides and currents were between February 7 and 15. It was thus natural that the operation should be carried out in this time period. The exact date had to be determined now according to the most favorable weather conditions.

Insofar as the German meteorologists had only the scantiest meteorological data from the long-range reconnaissance planes over the Atlantic, an exact weather forecast was extremely difficult. For this reason, three U boats were diverted from the Atlantic theatre of operations solely for weather observation and sent to the area of Iceland, the area that determines the weather. The weather reports, sent systematically, made an accurate forecast possible. The meteorologists could deliver a favorable forecast for the operation on February 7. Indeed, the forecast was better for the ships than for the airplanes. But since February 7, a considerable weather uncertainty had been existing because of a decrease in a Continental high-pressure area. It was decided that the group should sail from Brest at 2030 hours on February 11. The weather forecast now actually materialized, even though with a delay of about 6–8 hours. This sufficed, however, so that the fighter escort could be flown.

But we were not yet at that point. Shortly before the tugs were about to pull the ships from their berths, air-raid alarms were given, and, as always, the harbour area was camouflaged by a smoke screen. The ships could depart only after a delay of somewhat more than two hours. Then, however, the ships and the destroyers assigned for the escort were assembled faster than had been provided by the time schedule. During the night, thanks to favorable currents and a higher cruising speed, about one hour of the delay was made up. By 0600 hours on February 12, the task force turned on an easterly course at the latitude of the Cherbourg peninsula. During the night, navigation was made only by dead reckoning. The Luftwaffe staff on land could follow the advance of the ships by means of reports of the radar stations on the coast. Naturally, great joy prevailed about the diminishing delay, since now the units would not have to be transferred farther to the west; rather, the defense orders could be followed exactly as provided.

On the *Scharnhorst*, essentially nothing out of the ordinary happened from departure until sunrise; all went according to plan. Completely unnoticed, at least so it appeared, we sailed out of the harbour. Also, no messages arrived which would point to our having been observed. Our own radio-intelligence observed no unusual radio communications of the enemy. Thus, on board, the morale of the entire crew was high. Finally, after the long wait and lying in, we again had a sea trip which at least promised to be unusual (Figs. 1 and 2).

The intended navigational assistance by relay of bearing and distance by the great shore-based radar stations did not materialize. We learned later on that these measuring devices never did locate exactly the leading ship of the group. This shortcoming was also due partly to the very strict secrecy. The operators of these instruments could not be instructed in sufficient time about tasks completely new for them, so that no experience about this could be collected by them. This deficiency at no time impaired the navigation. Just before noon on February 12, we received a very good, and also exact, message from a radar station located near the area of Dieppe. Since at that very time dead reckoning was not confirmed by shore-based objects, this message was particularly valuable for a determination of our position.

By dawn, all ships were cleared for action. We expected, at least, to be discovered by enemy planes. Ac-

Fig. 1—Breakthrough up the Channel with torpedo boats and covering aircraft.

Fig. 2—Breakthrough up the Channel February 11–12, 1942.

cording to schedule, a torpedo-boat flotilla arrived and strengthened the escort of the big ships.

However, an unpleasant message suddenly slowed down the sailing. During the night, a mine-sweeping flotilla had located an anchor-mine-barrier exactly on the track of the group. Obviously, this had been layed recently. By reckless usage of his boats, the flotilla commander managed just in time to sweep a gap through the mine barrier and the group passed through, although at reduced speed.

From radio messages received, it was recognized that the responsible command posts of the Navy on land still reckoned with a delay of 90 minutes from the schedule. A destroyer got the order from the admiral to run toward shore, and from there to transmit radio signals with the correct position. This step was necessary so that from direction finding on this radio message the British could draw no conclusion as to the presence of war ships. The enemy was still quiet.

By 0900 hours, just at dawn, the first nightfighters appeared. In order not to be discovered by the British radar, they had strict orders to fly very close above the water. Moreover, complete radio silence was ordered for them. Special praise must be given for the exemplary radio discipline of the pilots. Contrary to their usual customs, the airplane pilots now sought to emulate the recognized good radio discipline of the Navy. The task force had not been discovered by radio emissions of the fighter escort, which from now on rotated duties. At about 1100 hours, as it had become light, the nightfighters were replaced and transferred to the area of Holland for refueling, in order to accompany the ships there again in the evening. The fighter escort had now been taken over by single-motored airplanes of the ME (Messerschmitt) 109 type. At this time the position of the task force was in the area of the mouth of the Somme, that is, still about 40 nautical miles from Dover-Calais.

Until then, we had once seen an airplane at a great distance, but it was not possible to determine whether it was one of ours or one of the enemy's. Quiet continued; the only problem was to take care in exact navigating. It was then said to me facetiously that it could well be an instruction trip for the quartermaster personnel! Indeed, we did not know then that in these morning hours a great electronic interference had set in which was helping us. Concerning this situation we must at this point report more in detail.

Immediately after the occupation of the French coast in 1940, special teams of the Signal Corps Luftwaffe and the Navy were dispatched to the Channel coast in order to determine whether instruments similar to our radar equipment had been established on the English south coast. Up to this time we had no clear understanding concerning these developments of similar equipment by the English! Very soon from places which had been furnished with receivers—we called these Radar Intelligence Stations—a number of English devices were discovered on meter and decimeter wavelengths. By systematic sorties and tracings over a period of time, an exact map of all existing equipment located within the range, together with their most important characteristics, could be set up. From these precise observations, we were able to deduce the most important conclusions about the development of the British radar devices!

Very soon we decided to jam these instruments, the character of which we had ascertained by Radio Direction Finding, by appropriate jamming equipment. These were developed; they were directly controlled by the frequencies emitted by the British equipment and could be tuned in in frequency, direction, and amplitude. Moreover, several airplanes were equipped with jamming equipment.

For the jamming of the radar equipment, which was recognized to be very strong, in the course of the year 1940–1941, stationary jamming equipment was established in Ostende, Boulogne, Dieppe, and Cherbourg (Figs. 3–6). These were equipped with very efficient directional beam antennas. The jammers were modulated with three groups of impulses in order also to achieve effective jamming at great distances, *e.g.*, from Cherbourg to the Isle of Wight. The impulse groups were synchronized with the search pulses of the British equipment. Through laboratory tests it was established that an object is very difficult to follow through such impulses. Originally these jamming installations were intended for the support of attacking German fighter units. The attacking airplanes were supposed to fly always on the line of sight between jammers and the British radar equipment, thus always in the center of area of confusion so that they would not be discovered (Fig. 7, page 7).

Moreover, three jamming aircraft of the Heinkel-111 type were on hand. With the help of search pulses of a British radar installation, the jamming stations could produce and emit five new pulses on the same frequency. The position and the amplitude of these five pulses relative to that of the received search pulses could be changed at will. Because of the fact that five such devices were installed in each airplane, each airplane could simulate 25 airplanes (Fig. 8, page 7).

These countermeasures were prepared by the senior signal officer of the air force for the breakthrough of the German task force. Both of the battle-ready jamming aircraft were prepared in Evreux, north of Paris. A bomber group of the Junkers-88 type was likewise transferred to that place. With this group, both jamming aircraft were to carry out an attack on the Harbor of Plymouth on the morning of February 12. Both of these airplanes started in complete darkness in advance of the bomber planes. Soon after the start, the well-known search pulses of the British equipment were received well. The signals stood still on the cathode-ray tube. Somewhere in the middle of the Channel, the jammer would be switched on according to orders. After

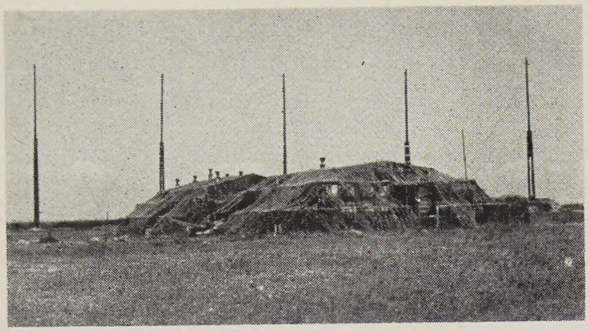


Fig. 3—Jamming installation, Breslau I, near Boulogne.

Fig. 4—Jamming transmitter, Breslau II, near Dieppe.

Fig. 5—Directional antenna of jamming transmitter, Breslau II.

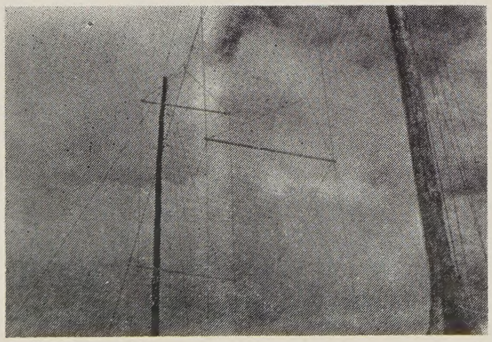


Fig. 6—Directional antenna of jamming transmitter, Breslau II.

a short while, the impulses which hitherto had been very quiet wavered. They altered their synchronized position, altered their amplitude, and changed occasionally to another frequency. The jamming stations could follow these changes without difficulty. During this time, both of the deception airplanes flew parallel to the English coast. Consequently, the British radio direction finders (RDF's) had the impression that a German bomber group was assembling there and preparing for an attack. During this time, the Junkers-88 of the attack forces could reach their goals unimpeded and fly back without losses. Of course, during the whole period, the British RDF stations held fast to the deceptive impulses and detected no others. At this time, the German war ships passed through the Bay of the Seine.

The jamming installations on land were ready for immediate use. They received the order to jam the radio direction finders assigned to them. On February 12, from 1000 hours on, these stations also had no notion why this jamming should take place. According to plan, they were switched on. In the course of time, all jamming stations naturally knew exactly the behavior of "their" British transmitters (the specific British transmitters monitored by a specific group), and furthermore, the frequency, the amplitude, and the type of modulation. After that, our own jammers were tuned in exactly. The RDF transmitter was continuously controlled by a monitoring receiver. Soon it was observed that in the case of several transmitters the phases or the amplitude, and even the frequency, were constantly altered. This was a sign that these stations strove to avoid the jamming. No countermeasures were taken against a few stations, two of which switched off completely. Suddenly a station was tuned in; it was presumably that between Eastbourne and Dover, which had not been observed for several months. As there were still jamming transmitters available, this could also be jammed. It looked, therefore, as if the British RDF equipment in some way had been confused by these countermeasures. It must be emphasized that jammers were at hand only for the known RDF stations on meter and decimeter wavelengths. The computing center at Boulogne had indeed observed a transmitter with 7 to 8 centimeters wavelength; for this there were still no jammers on hand. Enough about these countermeasures, which represented the first step for the pure high-frequency war.

Inasmuch as at the time of the jamming the German task force had not yet been discovered by the British, these jammings, which had been observed frequently, were no cause for suspicion of a particular military action. As a matter of fact, the first British radar station, located near Beachyhead, had discovered at about 1100 hours that several airplanes were circling over a ship, or groups of ships, which sailed by dead-reckoning at a speed of about 25 knots. As a result of this observation and the accumulation of reports about jamming of the RDF stations, the British began to

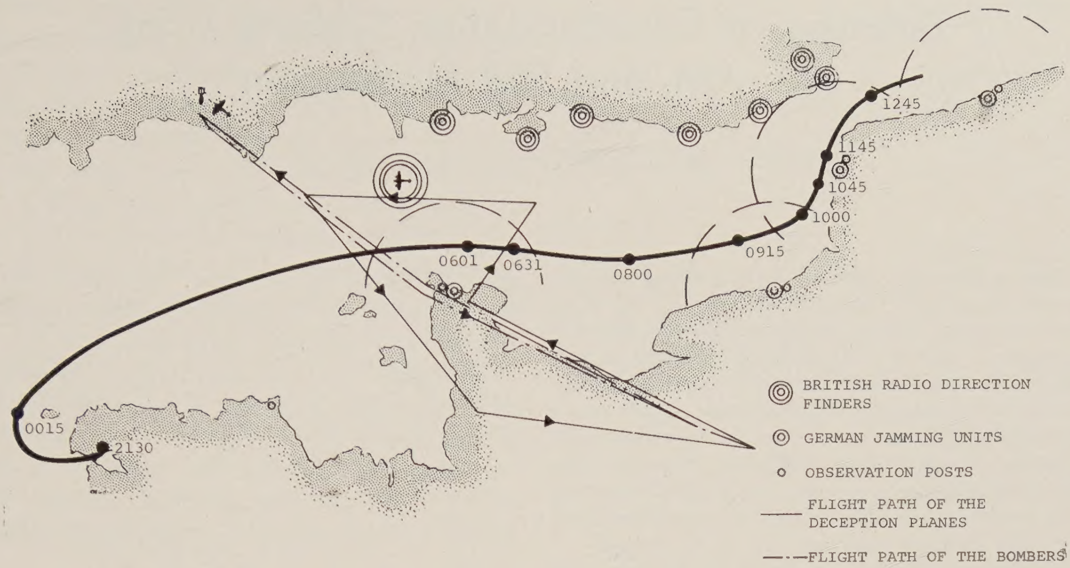


Fig. 7—Chart of the escape. The heavy solid line is the route of the German fleet.

Fig. 8—Jamming aircraft with five radio units each.

Fig. 9—Address of Vice Admiral Ciliax to crew of *Scharnhorst*, near Kiel after breakthrough up the Channel.

suspect that there might be something special going on in the Channel. Very gradually the alarm notices began coming in. Shortly before 1200 hours, the first significant reports concerning the sighting of a large group of war ships arrived at the responsible British Command posts. Only then did a reaction set in. But the German ships passed Cape Gris-Nez about 1300 hours! They had thus traversed the Channel for the first time in centuries!

From this point on, radio silence could be lifted. Nothing further needs to be said concerning this operation. The moments of uncertainty were over, for all practical purposes, after passing the Dover-Calais line (Fig. 9).

In Sir Robert's essay,[1] he described what a "blunder" had occurred. These shortcomings need not be repeated here. However, a lesson that may be learned is that again and again human failures or mistakes, particularly in military life, must be reckoned with. Since this boldly-carried-out operation of more than 15 years ago, enormous technical progress has been achieved in all areas. With this, the danger has also become greater that mistakes of a technical nature will occur, or that technical capabilities will be falsely assessed, so that the ostensibly best inventions could become ineffective through blunders. Today also, therefore, the famous slogan of Sir Robert should be taken to heart: "Give one the third best, the second best comes too late, the best will certainly never come!"

Jamming of Communication Systems Using FM, AM, and SSB Modulation*

HENRY MAGNUSKI†, SENIOR MEMBER, IRE

Summary—Jamming of voice communication systems is a very ungrateful task and "brute force" jammers have to be used, while other systems, such as radar, can be jammed effectively using low power but sophisticated jammers. Geographical situation is very much against the jammer, particularly in ground-based mobile communication systems. The propagation of ground wave is such that a rapid increase of jamming power is required, as the ratio of distances of the jammer to the desired transmitter increases. The jammer is never certain whether or not the communication network is jammed and is never actually able to jam the communications completely. It can only limit the operating range of the system.

Different modulation systems are considered and the necessary power density for jamming of each system is discussed. It is concluded that effective jamming of FM systems and other systems with threshold systems is easier than that of AM and, particularly, the SSB systems. However, for nuisance jamming, the opposite is true. Finally, the jamming of the SSB systems is considered in more detail and it is proven that the so-called reduced-carrier SSB systems are not easier to jam than systems with a completely suppressed carrier.

JAMMING of voice communication systems is an ungrateful task. Brute force jammers have to be used to be effective. This is true because at the receiving antenna the jammer always has to compete with the desired transmitter, and has to overpower it in order to prevent communication; otherwise it will be only a so-called nuisance jamming, which is of a questionable value. To jam other than voice communication systems, we can use sophisticated jammers of much smaller power. For example, in a radar system, we all know that the power reflected from the target and received by the radar receiver is very minute; therefore, it is possible to present the radar receiver with a multitude of false targets or even to saturate the radar screen with signals and completely confuse the radar operator, using a relatively low-power jammer at the airplane which wants to escape observation. The same is true for different data transmission and digital systems. Jamming, in this case, can be in a form of infrequent but strong pulses, which either upset the synchronization system of the data link or provide sufficient error rate to make the transmission worthless. But when jamming a voice communication system, we fight the human ear which can fish out the desired information from a very considerable amount of noise. Therefore, the jammer, to be effective, has to provide enough brute force power to cut communication continuously.

Different types of modulation systems will require different ratios of jamming power to the desired transmitter power at the receiver. In general we distinguish two basic types of systems, linear or proportional systems and the so-called threshold systems, as can be seen in Fig. 1. Systems based on amplitude modulation, such

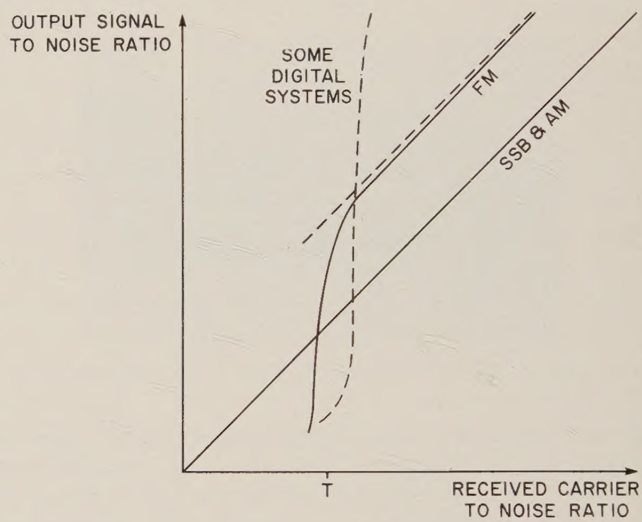


Fig. 1.

as AM and SSB, are linear because variations of the amplitude of the input signal provide equal variations of the output. All other systems are threshold systems. In a linear system the output S/N ratio is always proportional to the amplitude of the received carrier. In these systems, we can actually have a fractional S/N ratio, which means that the signal can be below the noise level and yet a certain percentage of words will still be understandable. On the other hand, every threshold system requires the carrier power to be above the noise power in order to receive anything. FM is a good representative of these threshold systems. Depending on the deviation used, the carrier has to be some 6 to 10 db above the noise to have any signal output. However, once the carrier exceeds this minimum value, we obtain a good signal-to-noise ratio because of the so-called improvement factor. FM is therefore, to a certain extent, a "go"

* Received by the PGMIL, June 6, 1960. Presented at the Natl. Conf. on Military Electronics, Los Angeles, Calif.; February 5, 1960.
† Motorola, Inc., Chicago, Ill.

or "no go" system, while amplitude-modulated systems are "soft." Soft systems are those in which the signal-to-noise ratio improves gradually in proportion to the carrier. Also, digital and other pulse transmission systems are definitely threshold systems; once the carrier is above the noise level, the error rate may decrease rapidly, and almost immediately a perfect output is obtained. It follows that the complete jamming of the FM or other threshold system will require less power margin than the jamming of a linear system because of the "capture" effect. On the other hand, if the nuisance jamming is considered, the FM system will suffer very little or no interference if the jamming power is below the desired transmitter power. Linear systems will be more sensitive to nuisance jamming but they can receive portions of the message even if the jamming power is considerably higher than the desired transmitter power. To obliterate the linear communication system, sometimes as much as 10 times more power has to be provided by the jammer than is supplied by the desired transmitter.

In considering a geographical situation, the distance of the jammer to the receiver is of utmost importance, as will be shown, since the geography is very much against the jammer. We must also consider propagation. Fig. 2 shows typical propagation curves. The free space propagation line shows that the signal decreases with distance at the rate of 6 db per octave (octave means doubling the distance); but to obtain this propagation both the transmitter and receiver have to be airborne. We will be mainly concerned with ground-based communication when both the transmitter and the receiver are ground-located, mobile, or portable units. We must consider, therefore, propagation over ground surface. The next theoretical curve on this figure shows this propagation over a smooth earth in which the signal decreases at a rapid 12 db per octave rate. However, in practice and based on many measurements, the heavy black curve shows us what happens. The signal decreases slowly at first and then decreases rather rapidly, always below the theoretical values. It is more reasonable to assume a slope of at least 15 db per octave. This value simply means that if the jammer, for example, is twice as far as the desired transmitter from the receiver to be jammed, it has to provide 15 db more power than it would have to provide to jam the receiver if it was the same distance away as the desired transmitter. This does not sound too bad, but let's translate it into the formula that is shown in Fig. 3. We can see that the distance ratio determining the jamming power is to the *fifth* power! K in this formula is a constant factor that takes into consideration such things as what the margin of the jammer needs for different types of modulation. Table I may be helpful in visualizing this situation. As the distance to the jammer increases, the jammer power must increase rather rapidly. Let us take a simple example and assume that the desired transmitter is two miles away and has a power of 20 watts, which is a reasonable assumption for a forward area Army net. Let us further assume that the jammer has to provide five times more power at the receiver to completely jam the desired transmitter. If we locate our jammer two miles away, it follows that it would have to radiate a power of 100 watts. But see what happens if the jammer is located eight or ten miles away! To perform the same function at ten miles, the jammer has to have 300 kw of

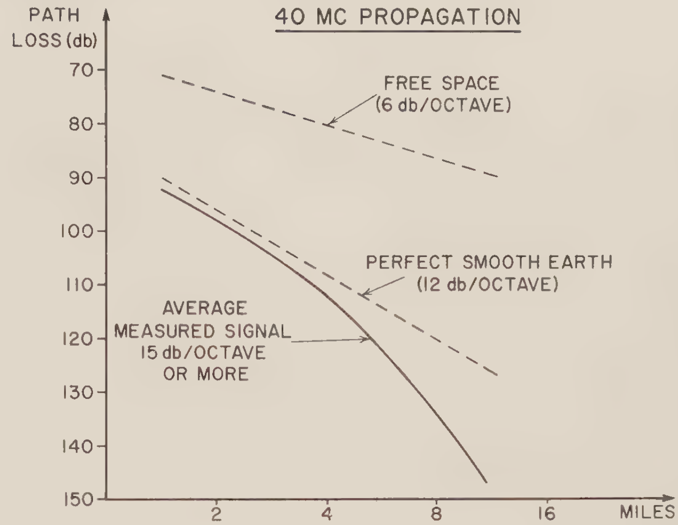
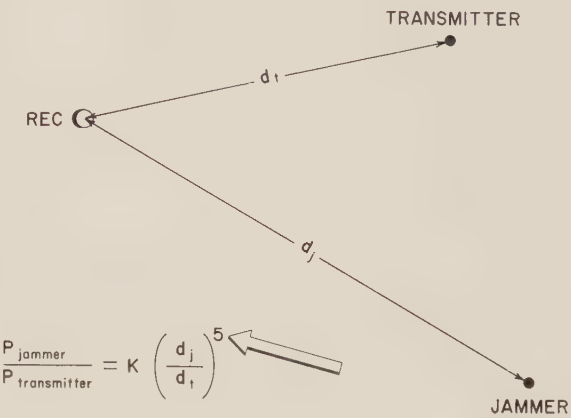


Fig. 2.



$$\frac{P_{\text{jammer}}}{P_{\text{transmitter}}} = K \left(\frac{d_j}{d_t} \right)^5$$

Fig. 3.

TABLE I
REQUIRED JAMMER POWER

Distance (Miles)	Relative Power (db)	Example of Power Needed
1	0	3.1 watts
2	+15	100 watts
4	+30	3.2 kw
10	+50	300 kw
20	+65	10,000 kw

power! From this table one can see that the geographical situation is of utmost importance.

Two other aspects of jamming communications are that the jammer is never certain whether it jams effectively and that a complete jamming is virtually impossible. The jammer can only decrease the communication range of any given system. For example, if the receiver, as shown in Fig. 4, is being jammed by a distant jammer, the friendly transmitter T_1 located in an area near the receiver (which is shaded) will be received by this receiver with nuisance jamming. It is granted that by using a very powerful jammer the range can be severely curtailed, but never completely destroyed. If, in the situation depicted by this figure, the jammer power is increased 30 times, the range of communication will decrease by a factor of 2, and the transmitter T_2 will still be received. We can see clearly that an infinite power of the jammer would be required to destroy communication completely over short distances.

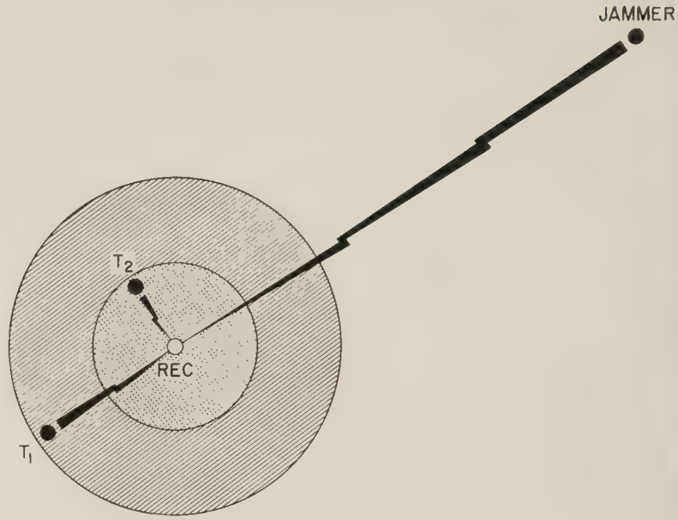


Fig. 4.

Now let us discuss how to jam most effectively. A well known principle states that the jammer, to be most effective, must employ the same type of signal and modulation as the signal it intends to jam. For example, if an AM system is to be jammed, a carrier which is amplitude modulated by noise will do very nicely to cover the voice modulation. The jamming power must be centered on the same frequency, and must be spread over the same bandwidth as that received by the receiver to be jammed. This introduces the concept of power density. We can see that certain adjustments of the jammer are necessary to provide maximum power density at the receiver. The center frequency of the jammer and the modulation depth must be adjusted, and, what is more important, the modulating noise bandwidth has to be limited in order to provide maximum concentration of power density where it hurts the most. If the noise bandwidth is not limited, the jamming power will be spread over a wide bandwidth, and the power density may not be sufficient for good jamming. Comparing FM and SSB, the power density of FM systems is much smaller than the power density of SSB, as shown in Fig. 5. Since the jammer is not certain of the center frequency of the system to be jammed, a certain margin of power is required as shown. This margin depends to a certain extent on the design and sophistication of the jammer, but it depends also on the frequency stability of the communication equipment. In order to jam positively, the power of the jammer has to be increased to provide for additional bandwidth. In the case of SSB this may lead to an appreciable increase in total jammer's power, since the carrier frequency of the SSB is uncertain and cannot be easily measured. Another reason for jammer power increase is the higher-power density of the SSB system.

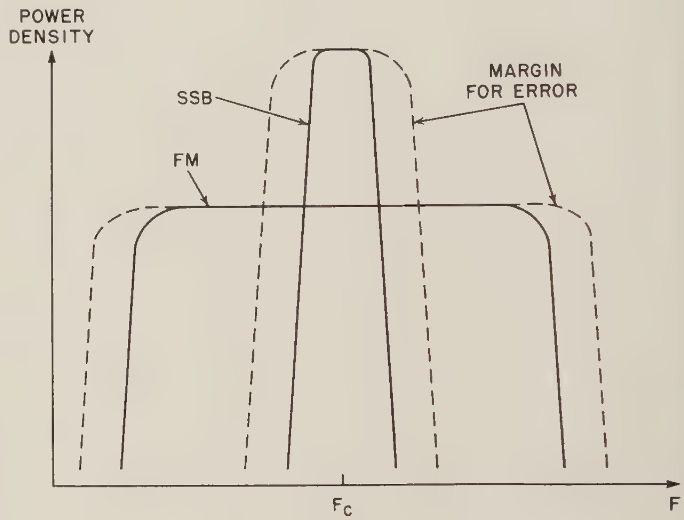


Fig. 5.

Another variation of SSB modulation is a reduced carrier SSB, sometimes called a synchronous SSB system. In such systems, a small amount of carrier is radiated in order to combat Doppler frequency shift and to provide distortion-free reception. The carrier may be reduced by some 10 to 20 db. The bandwidth of the receiver circuitry, which is phase locked to such a carrier, is very narrow—often less than 100 cps. Therefore, as shown in Fig. 6, the power density required to jam the reduced carrier is very high. The conclusion is that the reduced-carrier system is just as difficult to jam as any other SSB system. We can see that all SSB systems will be more difficult to jam than FM systems and will require a more sophisticated jammer. To help adjust the jammer to frequency, a direct telephone line between the jammer and the receiver to be jammed is sometimes used in the field tests. However, we could not expect such cooperation from the enemy during a war.

In summary, we draw the following five conclusions:

1) Brute force powerful jammers must be used to jam communication systems.
2) Linear systems such as AM and SSB are more difficult to jam completely than the threshold

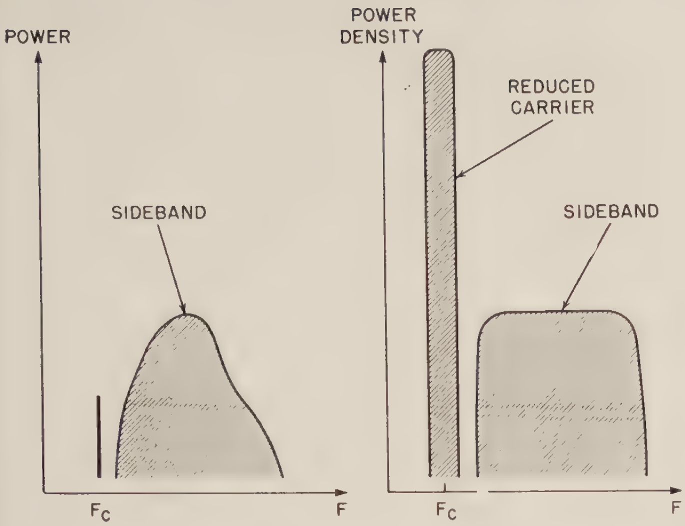


Fig. 6.

systems, but the nuisance jamming of such systems is easier.

3) Geographical situation is very much against the jammer. It must be close to the receiver, or else it must have an extreme amount of power.
4) Jammers can only limit severely the range of communication; complete jamming of a mobile communication system is not possible.
5) SSB systems are more difficult to jam than other systems. The radiation of a reduced carrier in SSB is not very helpful to the jammer.

Some say that communications should not be jammed at all because the intelligence obtained by listening to the enemy is very valuable. Maybe those who adhere to this principle know what they are doing. Certainly they are avoiding a lot of effort and trouble necessary to jam communications.

Improving Electronic Reliability*

MORRIS HALIO†, SENIOR MEMBER, IRE

Summary—**Each piece of military electronic equipment passes through various phases in its normal life cycle. These are: planning, design and development, pilot production, manufacture, transportation, storage, operation, and maintenance. Each of these stages is replete with opportunities for the introduction of unreliabilities. This paper points out the pitfalls which may be encountered and makes specific recommendations to avoid them, so that total potential reliability may be realized in the final equipment.**

Introduction

MOST OF US have been made aware of the growing complexity of weapons systems utilizing countless electronic circuits with myriads of parts and the terrifying reliability problems that arise as a consequence thereof. The reliability problem with its many facets is reminiscent of the many-headed Hydra. Each of these heads must be removed to conquer the beast. If one were to trace a piece of equipment through its life cycle, he might arrive at a flow chart such as that in Fig. 1 showing the stages of planning, design and development, pilot production, manufacturing, transportation, storage, operation and maintenance. Each of these presents an opportunity for additional unreliabilities to be introduced. It is obvious that if the design itself is such as to limit the maximum potential reliability to a certain value, then poor manufacturing processes or the deleterious effects of storage, for example, can only serve to reduce the ultimate reliability of the equipment. It is therefore imperative to minimize the unreliabilities introduced by each step in the process.

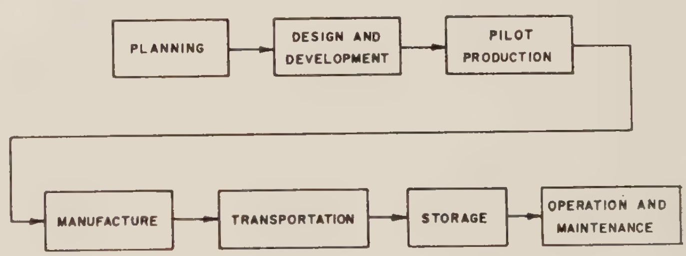


Fig. 1—Flow chart in life cycle of equipment.

At this point, it might be helpful to define some of the terms used in this paper. The first one, of course, "reliability." Definitions of this term vary from some long and complicated ones to the simple one, "When you press the button, it goes." The definition preferred by the author is that employed by one of the task groups of AGREE (Advisory Group on Reliability of Electronic Equipment of the Office of the Assistant Secretary of Defense), which is "Reliability of an item is the probability that it will perform without failure a specified function under specified test conditions for a required period of time." Incidentally, the various task

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groups of AGREE did not all agree on a definition for this term. Mathematically, $R(t)=e^{-t/m}$ where $R(t)$ is the reliability, t is the variable time, and m is referred to as the reliability index. The latter is defined as the average measure of the equipment failure rate expressed in mean-time-between-failures. The reciprocal of this quantity is known as the failure rate and is most conveniently expressed as number of failures per thousand hours.

Fig. 2 depicts a typical statistical curve of the variation of failure rate during the life of an equipment. The high rate of early failures is attributable to poor parts control, manufacturing techniques, inspection and quality control. At time A the defective parts have been eliminated, and the failure rate is essentially constant until time B when the failure rate begins to increase, signifying the end of useful life of the equipment.

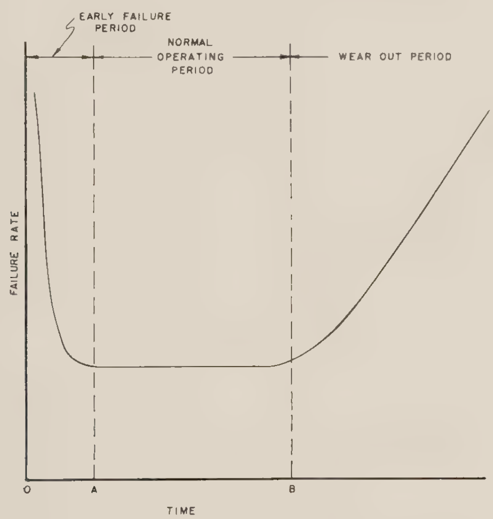

Fig. 2—Failure rate of equipment vs time.

The terms employed for the various subdivisions of an equipment are still not fully standardized and I would like to recommend the following definitions, which are modifications of those listed in Department of Defense Directive 3232.2:

Part: An item which cannot be disassembled without destroying its identity, *e.g.*, resistor, capacitor, switch, relay, socket, bearing, bolt.

Subassembly: An aggregation of parts mounted together for convenience and incapable of performing any function prior to incorporation into an assembly, *e.g.*, a terminal board with parts mounted on it, an IF transformer with tuning slug and mechanism.

Assembly: A combination of parts or subassemblies, or both, capable of performing a function, *e.g.*, amplifier, oscillator, modulator, filter, power supply, junction box.

Component: An aggregation of assemblies, constituting an element of an equipment and performing a function necessary to the operation of that equipment, *e.g.*, transmitter, receiver, rotating antenna, frequency standard.

Equipment: A group of components capable of performing a specified function, *e.g.*, a radar set, a gun director.

System: A combination of equipments which have the capability of performing a mission, *e.g.*, an anti-aircraft system consisting of radars, guns, missiles, interceptor aircraft, etc.

One will notice that the subdivision formerly known as "component" is now referred to as "part," while the term "component" is reserved for designating a group of assemblies.

Planning

The first phase of the reliability program is the planning stage. It is necessary that quantitative specifications for equipment reliability be incorporated into the development contract. The present low level of reliability may be partly ascribed to the failure to do so. In the past, a manufacturer who designed a new system had to meet certain performance specifications. However, he was under no legal obligation to include reliability among these. As a result, reliability has been treated as an afterthought. Long experience has shown that this is too late to improve reliability; once the design has been frozen, the failure rate of electronic equipment cannot be appreciably decreased by debugging. High reliability cannot be achieved unless this factor is taken into account during the preceding stages.

Reliability requirements should originate with the groups responsible for the operational requirements and military characteristics of the various services, since it is through these groups that the services must determine how they intend to accomplish their mission. The figures decided upon by the services must then be incorporated into the development contracts for new equipment. Proper planning is the foundation on which the reliability structure is based.

Design and Development

Design and development follow the planning stage. The reliability of the completed equipment will depend on that of the parts employed as well as the circuitry in which they are utilized. It is well known that the over-all reliability of an equipment where the parts are placed in series[1] can be expressed by

$$R_{\text{over-all}} = R_1 \cdot R_2 \cdot R_3 \cdot \cdots \cdot R_n;$$

i.e., the over-all reliability is the product of the individual reliabilities. The simplifying assumption has been made that there are no reliability interactions among the various parts. Evidently, for very complex equipments, the reliabilities of individual parts must be extremely high if the over-all reliability is to be tolerable. Fig. 3, which has been adopted from Lusser [3] shows the rela-

[1] A part is a series part if its failure would cause the entire equipment to fail. It is a parallel part if its failure would not necessarily lead to failure of the equipment, since it is shunted by another part.

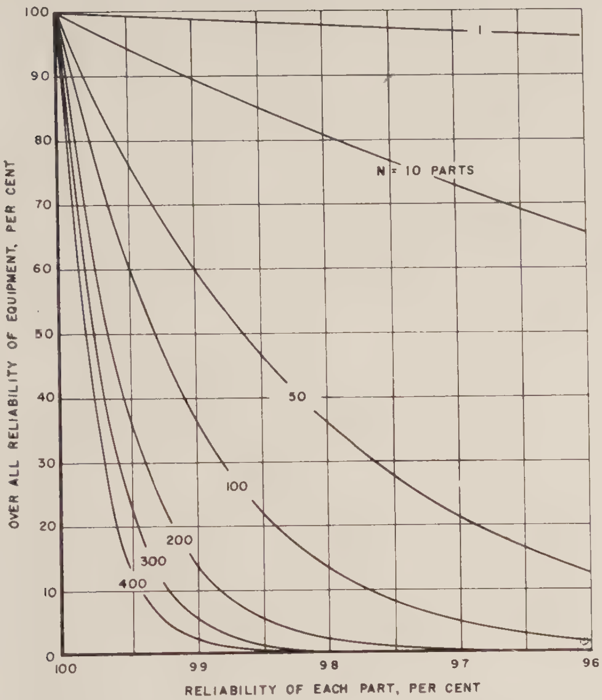

Fig. 3—Over-all reliability as a function of complexity and reliability of parts.

tion of over-all reliability to individual reliabilities for various degrees of equipment complexity. For simplicity, the individual reliabilities have been made equal. Notice that, for example, an equipment of 400 parts, each 99 per cent reliable, has only a 2 per cent over-all reliability. This emphasizes what is probably the most important concept in the study of reliability, *viz.*, that individual parts of a complex equipment must be of the very highest reliability. This means that the margins between the strengths and stresses must be sufficiently large. "Stresses" refers not only to mechanical forces, but also other parameters such as voltage, current, frequency, temperature, humidity, acceleration, vibration, etc., to which a part is subjected in use. The strengths are the values of these parameters at which failure will occur under the given conditions.

To determine whether a part to be used in an equipment is of acceptable reliability, a stress-strength analysis is recommended, and the following procedure is employed. A stress-scatter diagram is constructed as in Fig. 4, depicting the stresses to which the part will be subjected in the intended application. These data will have been obtained from field measurements. A frequency distribution curve is drawn and the mean and standard deviation calculated. Tests-to-failure are then conducted on a representative sample of the part whose use is contemplated, and the strengths plotted. The frequency distribution curve, the mean, and the standard deviation for the strengths are obtained. To determine the allowable margin between mean stress and mean strength, the standard deviations of stress and strength are multiplied by suitable factors depending on the required part reliability, and the products are

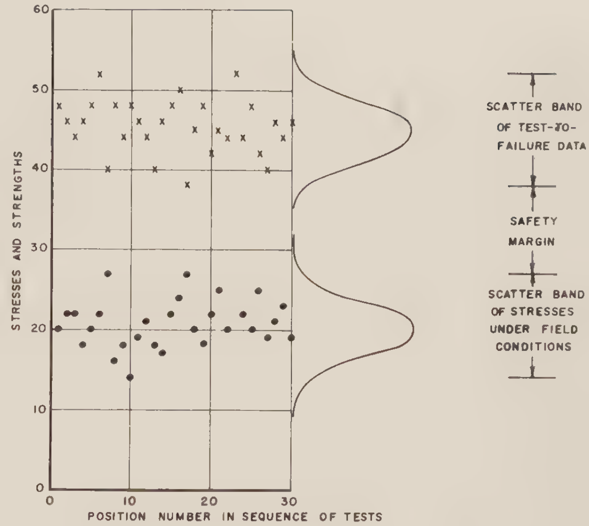

Fig. 4—Distribution curves of strengths and stresses.

added. Thus, the total permissible margin between the strength and stress means can be expressed as

$$M = K_1S_1 + K_2S_2$$

where M is the margin, K_1 and K_2 are the strength and stress factors, and S_1 and S_2 are the corresponding standard deviations. If the actual margin is less than the permissible margin, the part will have to be redesigned or replaced with a more reliable part. Stress-strength analysis of this type is of extreme importance in the effort to attain high reliability.

It would be extremely desirable to standardize parts of high strength and to have this information assembled in handbooks available to designers. A start has been made in this direction, but the trend will have to be greatly accelerated to meet the needs of the military. Vitro Corporation, RCA, Battelle Institute, and Inland Testing Laboratories are among those who are doing pioneering work in this field.

Subassemblies, assemblies, and components should also be subjected to tests-to-failure. However, the purpose of testing these is to discover failures caused by specific assembly effects, such as local resonances and ambient temperatures. Therefore, testing of these items is recommended only after it has been determined that parts of extremely high reliability have been employed under conditions of adequate margin of safety; otherwise this type of testing becomes very cumbersome, and failures attributable to part unreliability mask those caused by assembly effects.

Stress-strength analysis depends upon testing of parts to failure as contrasted to testing of complete equipments under operating conditions. Unfortunately, there has been too much reliance on the latter procedure as a means of seeking the achievement of reliability. This is to be deplored since testing-to-failure furnishes a much better means of attaining this goal. For one thing, it makes it possible to determine very quickly the modes

of failure and permit redesign so that reliable parts can be used in the equipment. The old bug-hunting methods depending on failure reporting of equipments tested under normal operating conditions would take forever to accomplish the desired result. In addition, testing-to-failure is far cheaper, since this method requires substantially fewer tests. Extensive flight testing of missiles, for example, can get to be rather expensive. Even then, the ultimate cause of failure is often not discovered. In short, testing-to-failure means that we can buy much more reliability for a fixed amount of money.

One of the ways in which part reliability may be improved is for the parts designers to refrain from devising universal parts. Design of a single part for several applications with widely differing specifications tends to make the reliability for each application lower than if a different type were built for each of them. A part is generally designed for universality of application for two reasons: 1) lower cost because of high quantity of production, and 2) the control processes that accompany mass production tend to improve the quality and consequently the reliability of the product. However, there is a certain level of production beyond which the quality remains essentially constant. Once this is reached, the faults of the multiplicity of functions of a universal part become evident. For example, in the case of electron tubes, a tube may be used in a dc amplifier or in a blocking oscillator. Clearly, the specifications are different for these applications When a tube is designed which is applicable to both of these uses, the reliability for each suffers. There is certainly sufficient demand for each type so that a different tube can be built for each application. It is therefore recommended that parts designers originate different types for widely varying uses.

Another step the circuit designer can take to maximize reliability is to select part types which have higher inherent reliability; *e.g.*, vacuum relays can be used in place of other types. Employment of solid-state devices such as transistors imparts certain advantages such as low heat dissipation and resistance to shock, in addition to long life. Probably the greatest advance to date in this direction lies in the field of molecular electronics. This type of device eliminates the need for internal connections and makes it possible to increase the reliability tremendously.

The total effect of parts tolerances plus drift due to aging may cause failure of a circuit in operation. For example, an oscillator may shift its frequency out of tolerance or may stop oscillating entirely; a flip-flop may reach such a condition that a prescribed pulse may fail to trigger it. To prevent such an occurrence, a design method known as marginal checking (developed by Lincoln Laboratory) is recommended. In this method, the allowable variation of a part is determined as a function of a selected circuit parameter, usually a supply voltage or a trigger voltage. In practice, the tolerance of one of the parts in the circuit is plotted against the variation in this marginal-checking parameter, as shown in Fig. 5. For various values of part deviation, the supply or trigger voltage is varied until the circuit fails to perform according to specifications. The locus of failure points separates the failure region from that of normal operation. In this manner, the proper design center value, as well as the allowable tolerances, can be determined. Universal employment of marginal checking by equipment designers is decidedly recommended.

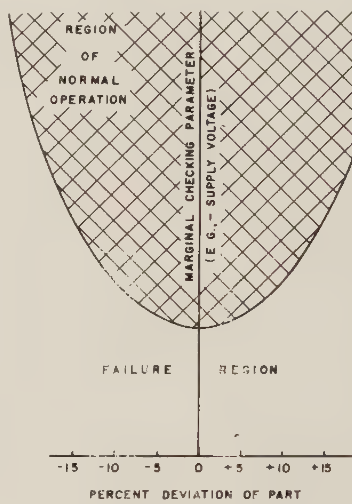

Fig. 5—Marginal checking—locus of failure points.

The foregoing discussion has been concerned with the reliability of parts. Some of the principles involved in the integration of these parts to form reliable equipment are as follows:

The first and most obvious precaution is to keep it simple. Granting that a given equipment will require a minimum degree of sophistication, the fact remains that there is still plenty of opportunity to "gild the lily." The temptation is great for our bright, inventive designers to emulate the Rube Goldberg approach. I fully sympathize with them, having done design work myself, and realize that designing for performance is much more interesting and glamorous than designing for reliability. However, the latter is one job that cannot be bypassed.

Equipment should not only be simple in design, but simple to operate. One of the causes of equipment unreliability is the maladjustment of controls because of the excessive number of front-panel adjustments which require an engineer's training to be correctly set. This is due to a design tendency to include controls which, when properly adjusted, increase equipment performance levels somewhat, but when maladjusted, reduce the equipment function to almost inoperable levels.

In addition to operability, the equipment should be designed for a high level of maintainability. The latter is defined as the reciprocal of the mean net time to repair failures. Expressed mathematically,

$$M = \frac{1}{\bar{x}} \quad \text{where} \quad x = \sum_{i=1}^{n} \frac{x_i}{n}.$$

Because of the increasing complexity of equipment and the generally decreasing level of skill of service personnel, it is necessary to make equipment easy to maintain. This presupposes the adoption by the designer of a disposal-at-failure maintenance philosophy. Circuits are designed as modules for ease of trouble-shooting and replacement. In accordance with this philosophy are the employment of printed circuitry, encapsulation, and miniaturization. It is recommended that specific maintainability requirements be included in development contracts for equipment.

The employment of theoretical reliability prediction in the initial design stages is invaluable. The technique consists of the construction of a functional diagram of the equipment in the form of blocks or units. The latter are assigned reliability values which are derived from known part-failure rates, and an over-all reliability figure is calculated. This permits the evaluation of potential designs on paper, thus weeding out the undesirable ones. This method not only saves time and money but results in a design which is inherently more reliable.

Another important principle is the practice of conservatism of electronic circuit design. Parts should be de-rated and tube voltages should be selected so that the lowest values which give the required performance will be employed. The latter step improves reliability in several ways: part failure is minimized because of reduced peak currents, lowered potential stress, and decreased heat dissipation, the likelihood of avalanche failure is greatly reduced, and the incidence of parasitic oscillations is reduced by the consequent restricted energy level. One manufacturer of television receivers was notorious for designing for stresses well above the reliability limits in order to conserve parts. Not only was the reliability of the receivers extremely low, but the maintainability was so poor that most servicemen were extremely reluctant to work on them. This approach is certainly not to be recommended for military equipment.

Redundancy is one method employed as a reliability measure. Two or more identical parts are placed in parallel so that failure of one part will not make the equipment inoperative. This is akin to moving the pitcher, shortstop, second baseman, and centerfielder all into line to field a ground ball; or to using both suspenders and a belt to keep one's trousers from falling.

It should be remembered that in many cases it is not possible to place redundant parts directly in parallel, so that a switching arrangement is required. The latter may introduce unreliabilities of its own which can severely reduce or negate the advantages gained by the use of redundant elements. In addition, there is a penalty to be paid of increased size and weight, not to mention the cost of the equipment.

Redundancy is a necessary evil and is recommended only for critical parts where every effort to achieve the required part reliability has failed.

Reliability considerations require that the parts in a circuit be integrated into a package which is designed with a view towards optimizing ruggedness and thermal adequacy. With respect to ruggedness, the design should be such as to restrict the maximum vibrational transmissibility (transmissibility is the ratio of induced to applied vibration amplitude) to a value as near to unity as possible. For example, the use of the clamped-type of assembly, where mounting boards are clamped at both ends, rather than the cantilever type, is recommended. The basic principle of adequate thermal design is to make the total equivalent thermal resistances from all heat-generating parts to the thermal sink or environment as low as possible. That is, adequate conduction, convection, and radiation paths should be provided to dissipate the heat. In most circuits, the electron tubes are the principal heat-generating parts, and their operating temperatures generally exceed the permissible operating temperatures of the other parts. Therefore, thermal adequacy begins with tube location. It is desirable to locate them as far as possible from the parts having the lowest permissible operating temperatures. Employment of equivalent thermal circuit diagrams in a paper analysis is of great assistance in minimizing cut-and-try methods in design. Proper packaging for ruggedness and thermal adequacy is a very important step towards equipment reliability.

Employment of standardized electronic circuitry by equipment designers can be very effective in achievement of high equipment reliability. The National Bureau of Standards and the Navy Electronics Laboratory have designed a variety of electronic circuits with the emphasis on a high order of reliability. These have been published in the "NBS Preferred Circuits Handbook" and the "NEL Reliability Handbook." A recent study of 83 pieces of Navy electronic equipment showed that 30 per cent of the circuitry could be performed by the circuits listed in these handbooks. It is recommended that the development of preferred circuits be extended and that equipment designers get in the habit of using these as much as possible. This may be a blow to the pride of designers who make a fetish of originality, but it will also be a blow struck against unreliability in their equipment. The use of standard assemblies which may be used in many equipments leads to a further gain in reliability because of the improved quality control which accompanies higher production levels.

Proper liaison is an important factor and its omission can contribute to unreliability. Liaison between designer and user is desirable to acquaint the designer with the user's environmental, operating, and maintenance problems. This is much more important with military equipment since a specific number of equipments are contracted for and manufactured before there is feedback from the user to the producer informing the latter of equipment shortcomings; whereas, in the case of commercial equipment, feedback begins with the first shipments of equipment so that design weaknesses can be corrected before large scale production takes place. I recall once having to redesign a piece of equipment after

pilot production had begun simply because the designer had not been aware of the conditions of operation of the equipment, with the result that the latter proved to be unreliable for the intended application. Proper liaison with the user would have obviated the difficulty.

Liaison among the various groups involved in the development of an equipment is important, too. RCA uses an elaborate system to ensure maximum reliability. After the development contract is awarded, the design engineer must justify his ideas before a panel of experts —reliability engineers; parts people; specialists in shock, vibration, and heat; circuit designers; etc. This is done before the design is started and also after the breadboard is ready. When the model is constructed, it is thoroughly tested: the results are reviewed by experts and analyzed in terms of the whole system. Weak points and lack of reliability are spotted. Undesirable interaction effects between various components of the equipment are eliminated. If found necessary, other tests are recommended, circuits are modified, packaging is changed. In the end, the equipment functions according to specified requirements. All of this review may seem to be unnecessarily time-consuming, but this procedure produces very large savings in re-engineering costs and, what is more important, results in a highly reliable product. Emulation of this philosophy is definitely recommended for all developers of military electronic equipment.

Pilot Production

Following development is pilot production of the equipment, the primary purpose of this stage being to enable the customer to get an idea of what may be available from regular production. It is also of benefit to the manufacturer in that it permits him to prove out the tooling and manufacturing processes.

In addition to the usual performance tests, a battery of environmental tests should be carried on to determine the reliability. These tests should at least include temperature and input voltage variation, vibration, and off-on cycling. Other environments selected depend on the corresponding service conditions and may include humidity, salt spray, sand, dust shock, radiation, etc.

Because of the inherent characteristics of the pilot production process, the output is unavoidably heterogeneous and the reliability tests are indicative of the capability of the manufacturing process rather than of acceptability.

Manufacture

In the area of manufacture or full production, the most obvious method of assuring that unreliabilities do not creep in during the manufacturing process is to practice adequate quality control.

Another step, which can be as important, is to survey and rate the vendors in the field, qualifying their products.

Automation can be of help in improving reliability. Investigations indicate that mechanized assembly techniques for electronic equipment tend to maximize reliability. These techniques include processed wiring circuitry, mechanized insertion of parts, automatic mass soldering, and automatic functional testing. Mechanized production and testing methods possess an advantage over manual methods in that the former avoid the irregularities in the techniques and materials of the latter, resulting in improved reliability.

One of the reasons for the existence of unreliable equipment is the tendency to rush it into production before the development has really been completed. Present procurement practices which aim to provide accelerated delivery of electronic equipment tend to minimize the time allowed for adequate reliability evaluation. This telescoping of development with procurement is accomplished at the expense of a sound reliability test program during the vital engineering phase and must necessarily be reflected in decreased reliability of the end product. Therefore, it is recommended that production be postponed until adequate engineering tests prove that the item in question fully meets the reliability requirements.

Transportation

The transportation phase furnishes an excellent opportunity for introduction of unreliabilities. The military services have experienced substantial damage to equipment during shipping, resulting from improper packaging and packing. Since the damage which occurs is not always detectable and therefore repairable, incipient failures may easily occur. Proper packaging and packing is an important link in the reliability chain.

The steps taken to ensure proper packaging design of the equipment to withstand operating shock and vibration will also serve to protect it during transportation. In addition, it is necessary to investigate the shock and vibration experienced by equipment packed and shipped in containers. It is recommended that instruments be developed which will record the amplitudes and durations of shocks to which equipments are subjected in shipment. These should be of a type which will operate unattended for a period of several weeks.

In addition, it will be necessary to determine specific dynamic values for a wide variety of cushioning materials for the use of designers of shipping containers.

The recommended research in packaging and packing should lead to increased operational reliability of electronic equipment.

Storage

Since production contracts provide for sufficient numbers of equipments not only to meet the current operational requirements but to allow an adequate reserve, it is obvious that the excess must be kept in storage for appreciable periods of time. This process subjects these items to the deleterious effects of corrosion, chemical

action, and other forms of deterioration, thus posing an additional reliability problem.

Equipment should be stored under conditions which minimize rate of deterioration. This sounds very simple, but it is a fact that these conditions can only be made known by 1) accelerated aging tests, 2) monitoring of items in storage. Accelerated aging tests are necessary to obtain data in a relatively short time during equipment development. However, since the conditions encountered during storage cannot be perfectly simulated, they are not a completely satisfactory substitute for storage monitoring.

In order to provide data on deterioration in a form which is readily usable by 1) the agency directly concerned with the given item, and 2) agencies which require such data as background information for similar items or subdivisions, it is essential that such data be made available in convenient form. The most suitable forms are considered to be punch cards or magnetic tape. At present, huge masses of information are buried in miscellaneous and heterogeneous reports in the archives of multitudes of agencies. As the number of equipments in existence increases, this situation will become greatly aggravated unless a streamlined system of data reporting and reduction is adopted. It is recommended that a working group be established at the Department of Defense level to develop such a system of data handling which will be uniformly employed by the various services, and designed to be compatible with the requirements of all the agencies. However, if such a plan is to succeed, it must be implemented by directive at DOD level which will make the use of the adopted system mandatory.

In order to provide maximum benefits from such a system, it would be advisable to retain a life history of each individual equipment from the time it is manufactured until it is removed from service by the operating unit. Only in this manner can a comprehensive knowledge of the variation in condition be obtained. The information that is obtained by the reporting sources will be transcribed to forms suitable for handling by computing machines, and subjected to statistical and engineering analyses. Results obtained will be in a form that can be used directly by designers, manufacturers, storage personnel, or operating agencies.

In order that the data obtained be valid, it is essential that the equipment used to test these items be of sufficient precision. Although the specifications for equipment in storage and operation are generally less stringent than those for acceptance, this should not imply that a corresponding decrease in precision of test sets used at these stages is permissible. All test sets used for any given equipment should be of similar accuracy, regardless of whether employed in the acceptance, storage, or operational phases. Only in this manner can trustworthy and comparable data be obtained.

Accuracy of measuring equipment presumes calibration against precise standards. In the interests of obtaining uniform results, it might be desirable to appoint a panel at the Department of Defense level to prescribe calibrating equipment to be employed. In fact, it may even be advisable to institute a Military Bureau of Standards, similar in function to the Calibration Division of the National Bureau of Standards but slanted towards calibration of the type of test equipment employed by the Armed Forces.

Another prerequisite for assuring validity of data is employment of high caliber technicians in the organizations performing the reporting function. This is contingent upon acceptance of the recommendations included in the Cordiner report dealing with the shortage of trained technicians in the Armed Forces. More will be said about this problem in the portion of the paper devoted to maintenance.

Another cause of insufficient reliability is that the design of suitable test equipment is usually treated as a secondary consideration. The testers are often not available until it is much too late to be of use in assuring reliability of the item. It is necessary that design of the basic equipment and its testers be treated integrally.

Operation and Maintenance

Maintenance is an important factor in the effort to achieve reliability, its purpose being to sustain designed performance and continued operation of equipment and systems in order to attain the highest degree of operational readiness.

Maintenance of electronic equipment is dependent upon such factors as equipment maintainability, personnel training, preventive maintenance procedures, and quality of support material such as technical manuals, test equipment, and test facilities.

Maintainability has already been defined as the reciprocal of the mean net time to repair failures. Unfortunately, there is nothing that maintenance personnel can do about this characteristic since it is predetermined. If the design people have been careful to observe the tenets of the disposal-at-failure maintenance philosophy such as modular construction, encapsulation, etc., then the maintainability of the equipment should be high.

Even if the design of the equipment enables relatively unskilled personnel to perform the maintenance function at the lower echelons, there is still need of highly skilled technicians at the top echelons. Unwise policies have permitted the situation to deteriorate to the point where large numbers of extremely expensive equipments are at the mercy of fewer and less skilled personnel than ever before. This grave situation can be alleviated only by taking immediate and drastic steps. The most effective one would be the decreasing of the high turn-over rate of trained men by offering sufficient incentive to remain in the services. This could be accomplished by raising the pay scales to realistic levels and by reinstituting the many fringe benefits which once were enjoyed. To assure that ability rather than longevity should be

the basis for promotion, a merit system should be adopted. Another very effective means of maximizing available skilled manpower is the elimination of the practice of requiring the technician to perform non-technical routine duties, such as K.P., guard duty, etc. A less direct, but nevertheless important, factor is the low level of technical background possessed by the average recruit, necessitating inordinately long training periods acquiring basic knowledge which should have been obtained previously. It is therefore advantageous to the Department of Defense to seek the adoption of better and more thorough training in mathematics and the physical sciences at the secondary school level.

Reliability can be greatly increased by detecting potential failures before they have an opportunity to occur. One of these maintenance techniques is called marginal checking and is related to the marginal checking performed during design.

The principle underlying marginal checking of electronic equipment as a preventive maintenance procedure is as follows. If all the parts are in good condition, variation of parameters (generally power supply or signal voltages) will not cause the equipment to fail. However, failure may be induced if a part has deteriorated, *e.g.*, if the transconductance has been appreciably reduced. The method employed is to vary voltages between specified limits and observe whether the equipment functions properly. For instance, in the checking of a computer, a problem may be fed to it while varying the voltage on portions of the computer in turn. An incorrect answer serves to localize the mal-operating circuit and then the potentially defective part.

Another technique which is being investigated is the prediction of imminent failure based on the variation of parameters of certain electronic parts. Armour Research Foundation under Air Force contract is conducting studies which indicate that resistor noise progressively increases prior to failure. It also appears that a decrease in insulation resistance of both resistors and inductors may be a harbinger of failure. Thus, monitoring of the equipment may provide a means of preventing failures by furnishing sufficient warning to permit part replacement. It is suggested that research along these lines be expanded, since application of these principles will be of great assistance in improving reliability.

Support material such as test equipment and training and instruction manuals are essential for the proper performance of the maintenance function. Yet, more often than not, these are not available simultaneously with the main equipment. Operation of the latter without the guidance furnished by the applicable technical manuals, and use of the proper test equipment, is not conducive to achievement of maximum reliability. Therefore, it is recommended that no equipment be released for distribution unless accompanied by the applicable support material.

The scope of the field covered in this paper is tremendous, so that it has been possible to touch upon only the highlights. However, if the recommendations which have been made were universally adopted, the reliability of our military electronic equipment would be greatly increased.

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Re-Entry Radiation from an IRBM*

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Summary—**The radiation emitted when a high-speed body re-enters the atmosphere is an important source of information concerning the physical processes taking place. Missile firings may be utilized to obtain some of this information. For about two years the Army Ballistic Missile Agency has conducted a measurement program known as Project Gaslight which has utilized Jupiter firings and, to a limited extent, both Thor and Polaris firings also. An account is given of the instrumentation employed and of some of the results that have been obtained. These include radiometric data in several wavelength bands from the ultraviolet to the infrared, and spectra in the visible. Motion pictures provide a record of the spatial relationships of the re-entry bodies, and these results are interpreted in terms of the impulse causing the initial separation. In the case of the Jupiter missile, there are two separations resulting in three bodies, the thrust unit, the nose cone, and an intermediate section or instrument compartment. Selected frames of the motion picture records show these bodies and give a qualitative understanding of the relative radiation from each source, of the disintegration and burning up of the thrust unit and the instrument compartment, and of the markedly lower drag-to-weight ratio of the nose cone. Forward scattering, presumably by high cirrus clouds, is shown to increase considerably the size of the very bright images. Most of the measurements have been made from ships, although some instrumentation has been airborne and photographs have been made from a distant island. Some of the difficulties in operations and in interpretations are mentioned. A more extensive evaluation of the data is in progress and plans are being made for future tests.**

Introduction

THE re-entry of high-speed missile bodies into the atmosphere has engaged the attention of various groups in industry and in government laboratories for a number of years. Much work has been done with special wind tunnels, field experiments, and theoretical studies. Nose cones of the "ablation" and "heat sink" types have been designed and tested. The first of these to be recovered after a typical IRBM re-entry experience was of the ablation type. In August, 1957, a scaled Jupiter nose cone was launched at Cape Canaveral by the Army Ballistic Missile Agency with a Jupiter-C rocket, and the unit was recovered by vessels of the U. S. Navy. This event was such an historic "first" that President Eisenhower saw fit to display the recovered nose cone on a nation-wide television hook-up.

The success of this recovery provided the principal impetus for a field measurement program by the ABMA. Project Gaslight was organized in the fall of 1957 to measure the radiation emitted by the Jupiter re-entry bodies and thus to learn more concerning the physical processes involved. Field measurements began with the night firing of the first full-scale Jupiter missile in May, 1958. Since then, similar observations have been made of ten firings, including two daylight Polaris missiles and both a daylight and a nighttime Thor. This paper gives some idea of the scope and results of the work under Project Gaslight and of the kind of information that can be obtained from relatively simple instrumentation in the field.

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Instrumentation

In the Gaslight program, photographic, photometric, and radiometric observations have been made over the spectral range from the ultraviolet to the infrared. The work has been a joint service effort. At the Atlantic Missile Range, the Air Force has provided support facilities, especially for instrumentation on one of their range telemetry ships, the M/V *Swordknot*. The Navy, in addition to handling the recovery operations, has also provided logistic support for instrumentation and personnel on several of their vessels, including a destroyer, the U.S.S. *Stickel*, and a tanker, the U.S.S. *Severn*. The technical groups participating with ABMA were Aerojet-General Corporation, the Avco Research Laboratory, Barnes Engineering Company, Bendix Aviation Corporation, the Cambridge Research Center, and the Army Rocket and Guided Missile Agency.

Because of the interest in making measurements as soon as possible, the initial instrumentation consisted of readily available components.[1] Visual acquisition and manual tracking were tried and found to be reasonably effective and satisfactory, though modifications and additional instrumentation were added in later tests. The choice of instrument location came from a compromise between the desire to be close for higher radiant intensities and the necessity to be to one side to avoid very high elevations in tracking. Thus, most of the measurements were made on board a ship near the impact area. However, some use was made of the Island of Antigua in the British West Indies, and attempts were made to use airborne instrumentation.

Ordinary 16-mm and 35-mm motion picture cameras, with both black and white and color film, have provided documentary evidence. Frame-by-frame pictures also give a quantitative measure of the separation of the re-entry components as a function of time. The familiar ballistic camera, otherwise known as a star or meteor camera, was used extensively. It consists basically of a wide-angle lens, a shutter for time exposures, and a photographic film or plate. Because the camera has a fixed mount, it records a moving luminous body as a streak. However, the roll and pitch of the ship in the

[1] See "Instrumentation Report, Project Gaslight," Barnes Engineering Company, Stamford, Conn.; 1959.

Gaslight tests introduced a sinuous motion to the record which was used as a rough timing indication in separating two or more streaks. In most cases the ballistic camera was made into a spectral instrument by the addition of a suitable transmission grating over the objective. This arrangement enables streak spectra of the glowing objects to be obtained in addition to the lines across the film from the zero-order image. A light chopper in front of the camera provides regular interruptions in the record that serve as timing signals. An arrangement of four such spectroballistic cameras is shown in Fig. 1. These are surplus F-8 aerial reconnaissance cameras modified by removing the shutters and substituting solenoid-operated blocking shutters. The two-blade chopping arm is run at 100 rpm, and the replica gratings have 300 lines/mm and are blazed in the first order for 6000 A. Both prisms and transmission gratings have been mounted in front of the lenses of motion picture camera to convert them to cine spectrometers. This enables target structure in the direction of motion to be resolved. For example, many of the targets leave more or less faint trails which are superposed on the main streak of the ballistic camera and thus not shown. Also, two targets may re-enter essentially along the same apparent line of motion, and thus be confused. One-pulse per second timing marks are impressed on the edge of the film when accurate image correlation is desired.

A number of photometers using photomultiplier cells as receivers and interference filters to isolate selected bands were used to cover the spectrum from 3600 A to 10,000 A. Fig. 2 shows the Avco Mk II equipment of this kind. Both the six-channel and the two-channel photometers were mounted on gun stocks and hand held. Infrared radiometers with lead sulfide, cooled indium antimonide, or lead selenide detectors, have been used. For example, Fig. 3 shows two Aerojet-General radiometers mounted on a tripod with a sighting telescope and a motion picture camera. The smaller one is the M-2B which was used on most of the Gaslight tests. It covers the range from 1.8 to 2.7 microns with a lead sulfide cell. The M4D-R1 uses a cooled PbSe cell and covers the band from 3.3 to 5.1 microns, as defined by an interference filter and the response of the cell. On the Navy ships, the Mk51 gun director was a favorite mount for cameras and radiometers. Fig. 4 shows the Barnes Engineering equipment mounted in this way on the U.S.S. *Stickell*. A four-inch PbS reticle-chopped radiometer is in the rear, with a photometer and boresighted cinecamera also in view.

Finally, a closed-loop TV camera system, the "Lumicon," which was made and supplied by Bendix, was used. Fig. 5 shows the camera, which uses a General Electric type Z5294 image orthicon as the pick-up element. It is sensitive to visible radiation and can detect 7th magnitude or brighter stars. The output of the camera is displayed on a monitor console not shown, and this, in turn, is photographed by a kinescope recording camera at 30 frames per second.

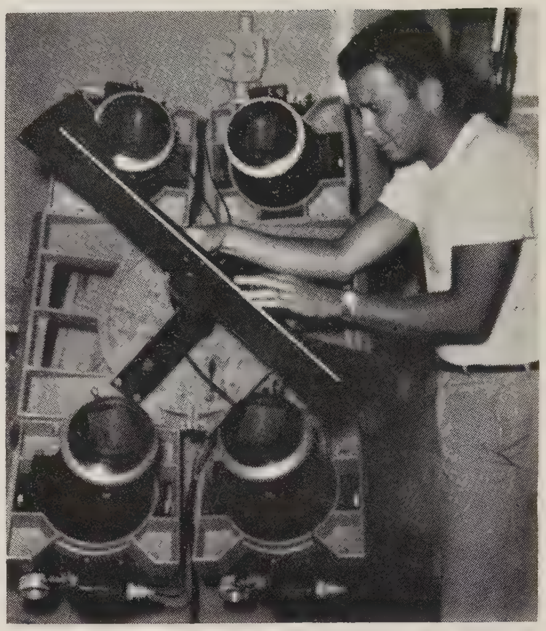


Fig. 1—Barnes Engineering Company arrangement of four F-8 aerial reconnaissance cameras employed as a spectroballistic camera of large field. Twelve-inch focal length $f/5$ Aerostigmat lenses and 300-line/mm Bausch and Lomb transmission gratings are used.

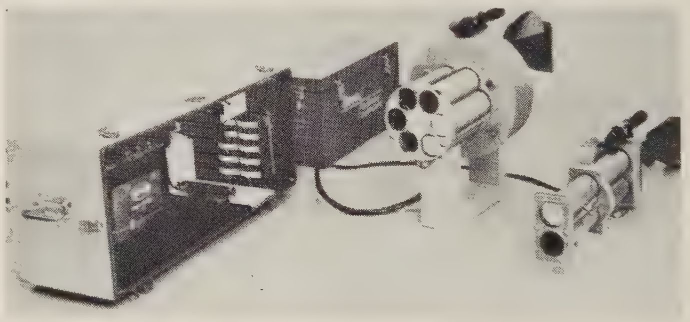


Fig. 2—Avco Research Laboratory Mark II radiation recording system. The two gunstock-mounted radiometers cover the range from 3600 A to 10,000 A in 8 bands. A Cine spectral 16-mm camera photographs the radiometer intensities and timing signals.

Results

In general, trajectory information and details of missile design are classified at this time. Thus, it is not possible to give altitudes and velocities in connection with the results below. With the exception of one Thor firing, all of the information concerns Jupiter firings. To give a more complete record of one test, most references are to the first Gaslight test of May, 1958.

Fig. 6 shows a typical plan view at the measurement impact area. The visible trajectory and a suitable location for the measurement ship are indicated. Fig. 7 shows the full-scale Jupiter, designated the AM-5, which was fired in May, 1958. The cylindrical part is the booster which is separated from the conical section just after burn-out. Subsequently, this conical section is rotated by small air jets until its axis becomes parallel to the trajectory direction at re-entry. Then a second separation takes place between the nose cone proper and the so-called instrument compartment. These two bodies

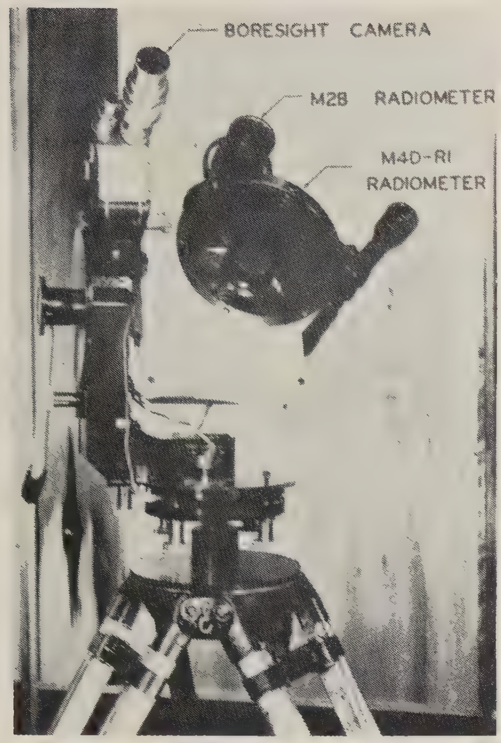


Fig. 3—Aerojet-General infrared radiometers with sighting telescope and motion picture camera used in Project Gaslight. The smaller radiometer is the M-2B covering the 1.75 to 2.6 micron band with a PbS detector. The M4D-R1, with a cooled PbSe cell, records the energy in the 3.3 to 5.1 micron band. The camera is a Bell and Howell Model 70 KRM/16 mm.

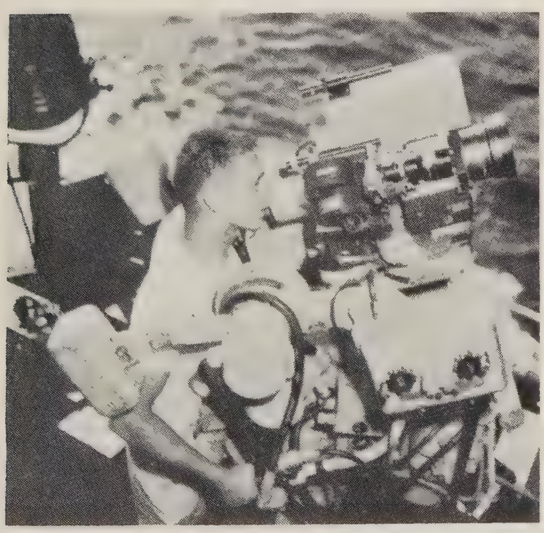


Fig. 4—Barnes Engineering Company equipment on the Mk51 gun director of the U.S.S. *Stickell*. The Model R-4K1 Wide Field Radiometer is mounted behind a photometer and cinecamera. It has a 4-inch aperture, 8-inch focal length, 4° field and a bandpass from 1.8 to 2.8 microns with PbS cell.

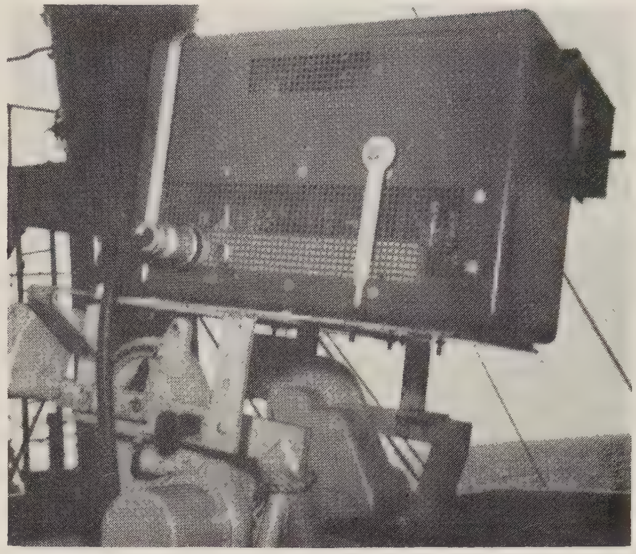


Fig. 5—The Bendix "Lumicon" camera used in Project Gaslight.

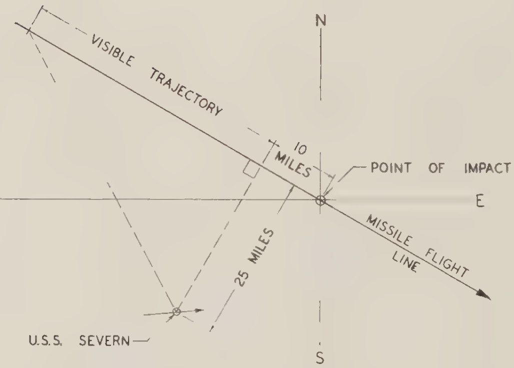


Fig. 6—Plan for Gaslight test AM-6A. Location of U.S.S. *Severn* relative to missile re-entry.

Fig. 7—The Jupiter Missile, AM-5, fired May 18, 1958.

are roughly comparable in weight and in axial lengths. One expects the nose cone, with its superior weight-to-drag ratio, greatly to outperform the other two. The nose cone does not encounter sufficient air drag to emit visible radiation until a relatively lower altitude is reached, and it will pull ahead of the other components after re-entry. The center of gravity of the booster, which is a shell with almost empty fuel tanks is near the nozzle end. Thus, this body is expected to orient itself during the early stages of re-entry and behave something like a nose-heavy arrow. The instrument compartment, with relatively thin protection at each end, should be ballistically the poorest and should disintegrate comparatively easily.

Some selected frames of the re-entry bodies of AM-5, which were taken with a Bell and Howell 35 mm Eyemo camera, are shown in Figs. 8 to 11. The booster and instrument compartment were sighted together before the nose cone appeared. Fig. 8 shows the booster and instrument compartment about 10 seconds after sighting. Both bodies are already intense sources, the booster giving some evidence of streaming action due to molten or burning debris that loosens and falls behind. About three seconds later, as shown in Fig. 9, the nose cone makes its appearance ahead of the booster, and the instrument compartment begins to show streaming action. The spatial arrangement is to be expected when it is recalled that the nose cone and instrument compartment separate along a line parallel to the re-entry trajectory. Furthermore, the booster should follow fairly closely the center of gravity of the other two bodies unless the impulse imparted to the booster at the first separation is considerable. Fig. 10 shows the situation about two seconds after that of Fig. 9. The booster has become

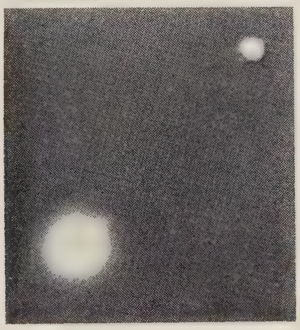


Fig. 8—The booster (lower left) and instrument compartment of AM-5 about 10 seconds after sighting. A Bell and Howell 35 mm. Eyemo Cine Camera with an 8.5-inch focal length, $f/3.9$ lens was used.

Fig. 9—Nose cone appears ahead of the booster, about three seconds after Fig. 8.

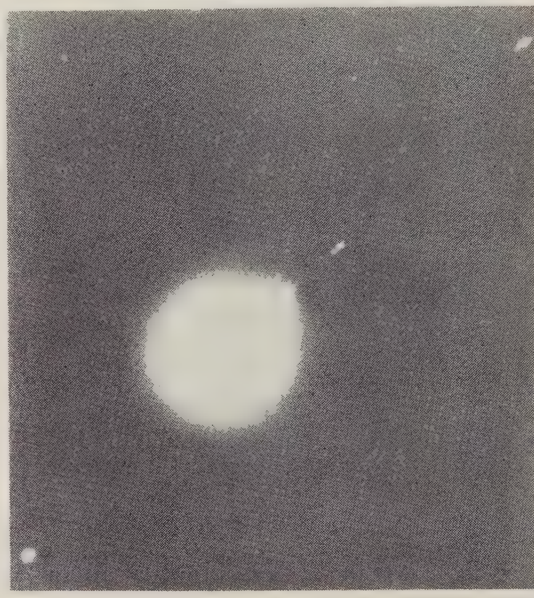


Fig. 10—About two seconds after Fig. 9. The booster is very large, as if it had exploded. The instrument compartment is breaking up and falling behind. The nose cone, which has become a more intense source, is moving ahead.

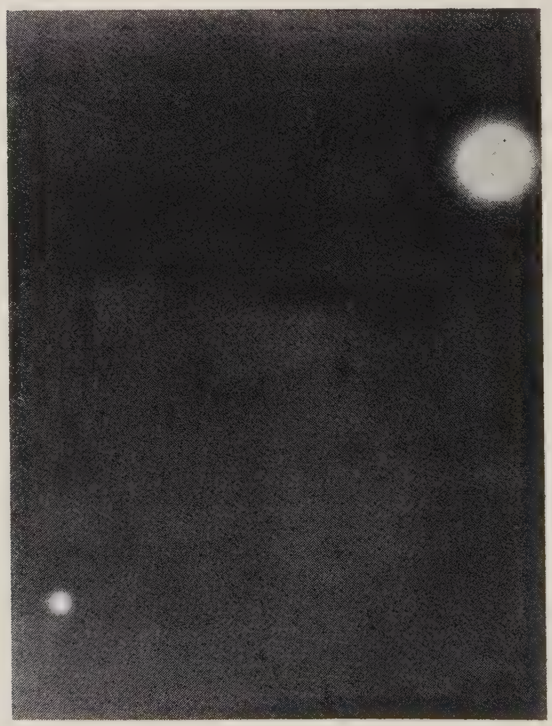


Fig. 11—About three seconds after Fig. 10. The nose cone is brighter and still further ahead of the booster.

very large as if the fuel tanks had exploded. The instrument compartment is breaking up into pieces and rapidly falling behind the booster. The nose cone has become more intense and is moving farther ahead of the booster. About three seconds later, only the booster and nose cone are visible, the latter even brighter than before, as shown in Fig. 11.

On the next firing, the count-down was so delayed that it was almost dawn at the impact area when reentry took place. Fig. 12 shows the three bodies against a background of scattered sunlight. A completely different spatial arrangement is perceived which was unexplainable until the telemetered results were analyzed. Apparently, in this case, the first separation was not a clean break. Since the center of gravity of the instrument compartment and nose cone is below and ahead of the booster, a component of momentum at right angles to the trajectory was imparted to the conical section in the first separation. In addition, the gyro reference was disturbed, and the second separation took place at the wrong orientation. The figure is shown principally to call attention to the extended after-trails that are visible because of the solar illumination. The trails persisted for several minutes, as shown by Fig. 13, which was taken about two minutes after re-entry. The effect of winds in shifting different parts of the trails can be seen.

Fig. 14 shows a re-entry picture taken with a ballistic camera on Antigua in January, 1959. No grating was used in this case. The upper line is the instrument compartment with the nose cone showing almost as a continuation of this streak. The booster re-enters below the other two bodies, because a vernier thrust engine was used which gave the nose cone a last increment in velocity after the first separation. The effect is to push the booster behind so that it re-enters with relatively less range. This time exposure shows the high cirrus clouds that are always present in the Caribbean area, even on a "cloudless" night, as was the case for this test. The forward scattering from these clouds is believed to account for much of the size of the images of these intense sources as shown in the previous figures.

A typical record from a shipborne ballistic camera is shown in Fig. 15. This was taken in May, 1959, from the U.S.S. *Severn*. The three traces are shown in the expected order, and of course the roll and pitch of the ship produce the curves in the otherwise straight streaks. The ship's motion serves as a rough timing mark so that

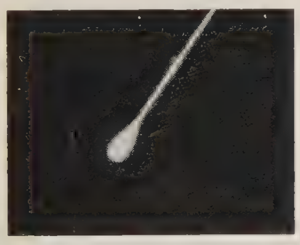


Fig. 12—Re-entry of AM-6A (July 17, 1958) at dawn. The scattered sunlight made the trails visible. At the lower right is the nose cone, with negligible trail. The larger of the other two is the booster.

Fig. 13—After re-entry the trails of Fig. 12 persist, showing wind motions in the upper atmosphere.

Fig. 14—The re-entry of CM-21 (January 21, 1959) as seen by a ballistic camera on Antigua, BWI. No grating was used. The lower line is formed by the booster, and the nose cone record seems to be almost a continuation of that of the instrument compartment.

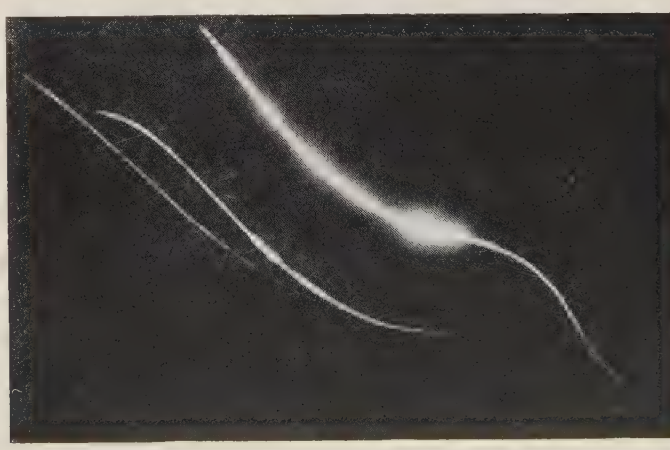


Fig. 15—Ballistic camera record of AM-17 (May 14, 1959) from the U.S.S. *Severn*. The roll of the ship makes possible a rough estimate of the locations of the three bodies as a function of time. The star traces record the motion of the ship.

the relative positions of the three bodies can be correlated to some extent. On this test a number of flash cartridges were incorporated into the nose cone and arranged to fire at regular intervals. The original negative shows these very clearly. They identify the nose cone positively, serve to locate it before it becomes self-luminous, and provide time differences along its trajectory. The onset of the visible light from the nose cone is gradual. An example of the kind of spectra obtained with the spectroballistic cameras is shown in the composite picture in Fig. 16. In this earlier test, six cameras were used, one of which was incorrectly aligned so that its picture had to be fitted to the others, as shown. The three zero-order traces are clearly visible, and the first-order spectra on each side are recorded.

The kinds of results that can be obtained with a cine, spectrometer on board a ship are shown in Fig. 17. In this case a prism giving a dispersion of 300 A/mm was used instead of a grating so that there is only one image.

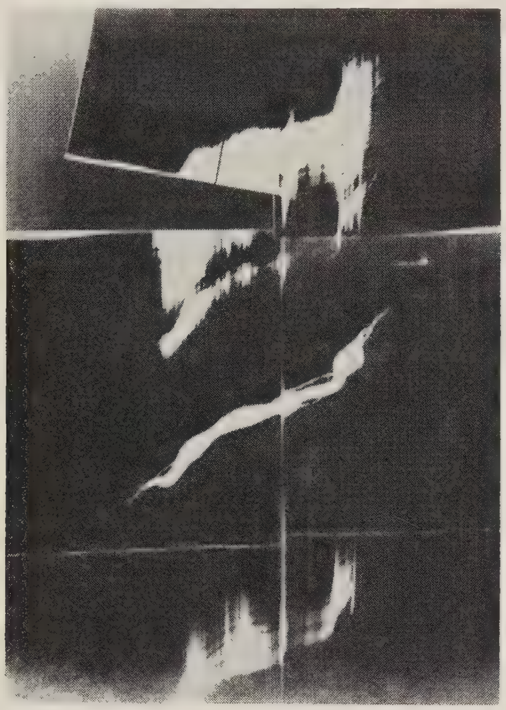


Fig. 16—Spectroballistic record of AM-5. One camera was incorrectly aligned, as shown.

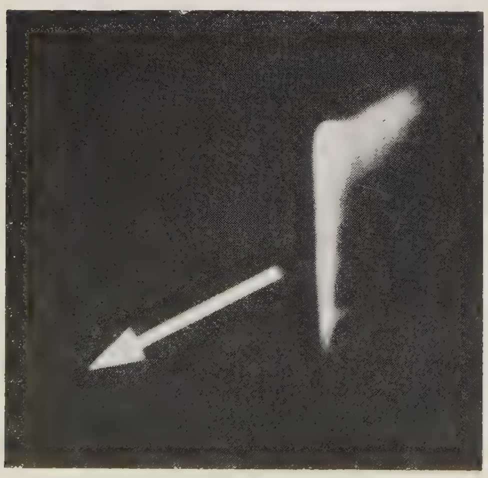
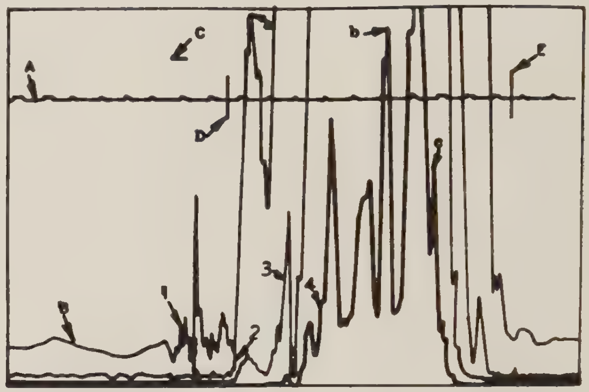


Fig. 17—Cinespectrometer record of AM-5 using a prism with 300-A/mm dispersion showing trails in certain color bands. The longest trail is at the red end of the spectrum. The direction of motion is shown by the arrow.



A = time pulse correlated with Patrick AFB standard timing pulses: 1 pip per second
B = background noise level
C = time when re-entry bodies were visually sighted
D = time when re-entry bodies were first acquired with M-2B radiometer
E = time at which re-entry bodies IR radiation was attenuated due to clouds

RADIANT INTENSITY LEVELS

a = 14 kw/ster, b = 737 kw/ster, c = 429 kw/ster

RADIOMETER RECORDING CHANNELS

(Attenuation Ranges)

1 = 0–10	3 = 0–1000
2 = 0–100	4 = 0–10,000

Fig. 18—The M-2B radiometer record of the radiation from the three bodies of AM-5. There are four traces involving four decades of sensitivity.

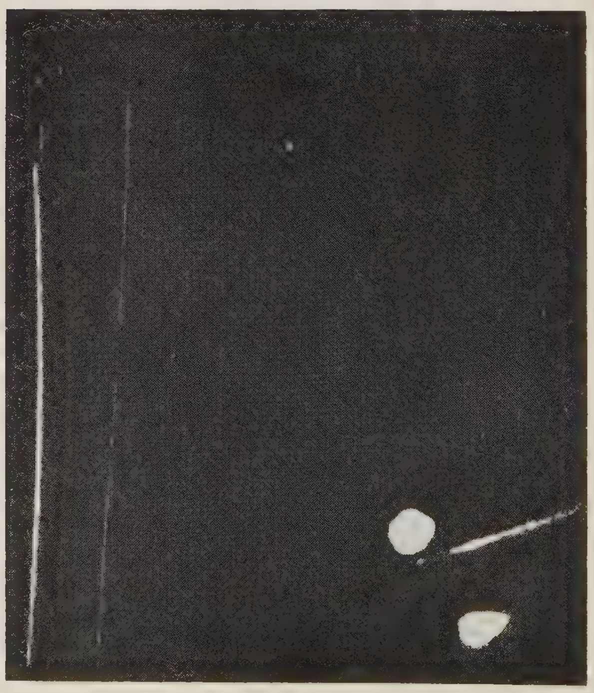


Fig. 19—A view of the Thor No. 184 re-entry with the Bendix "Lumicon."

The flag-shaped record shows a pronounced red trail as well as smaller trails in three other color bands. Probably these trails are due to the molten or burning debris previously noted as characteristic of the booster and instrument compartment.

An example of the kind of record obtained with a lead sulfide radiometer is shown by the M-2B results for AM-5 in Fig. 18. There are four traces here representing four decades of sensitivity. In spite of this large range, about $\frac{1}{2}$ second of the record was lost (off scale). This peak probably resulted from the explosion of the booster that was pointed out in Fig. 10. As in Fig. 17, radiation from all three bodies was collected so that, for the most part the record represents booster radiation. Some rather rapid fluctuations in the radiation are indicated which were probably associated with the streaming debris from the booster and instrument compartment, and with oscillations or rotations of these bodies. The record shows some "hesitations" in the ascending or descending portions which are apparently due to quite short fluctuations of duration less than the 0.1-sec time constant of the amplifier and recorder in this case. An example of the results obtained with the Lumicon is shown in Fig. 19 from a night firing of a Thor missile. Some uncertainty exists as to the interpretation of this picture as the central streak was not recorded by a motion picture camera at the same location. The pictures of this latter camera clearly show the two large objects, however. They fluctuated in intensity and left behind short wakes of streaming material much as the Jupiter booster does. At a later time the upper body broke into two seemingly equal pieces, and then the records were lost because of clouds. Thus, it is likely that these bright objects are two major sections of the Thor booster formed during an earlier stage of re-entry. If this is the case, it seems that the central streak was made by the "heat sink" nose cone used. Such an extended luminous after-trail is in marked contrast to the behavior of the ablation type nose cone of the Jupiter, as shown in Figs. 9 to 11.

Plans are under way to continue Project Gaslight on the Woomera Range with the enthusiastic cooperation of the British and Australians. Here it will be possible to locate the instruments precisely and to realize much more favorable conditions for the measurements. For example, cumulus cloud conditions, which often result in losing the bodies at lower altitudes on the Atlantic Missile Range, will be largely absent. Also, there should be much less forward scattering from the higher cloud formations so that the camera records will be more faithful. Furthermore, corrections for atmospheric attenuation in the infrared should be somewhat more reliable on this desert range.

Contributors

Warren N. Arnquist was born in New Richmond, Wis., on August 12, 1905. He received the B.S. degree in physics and mathematics from Whitman College, Walla Walla, Wash., in 1927, and the Ph.D. degree in physics from the California Institute of Technology, Pasadena, in 1930, where he was a teaching fellow.

W. N. Arnquist

He then became assistant professor and later associate professor of physics at Auburn University, Auburn, Ala. (formerly the Alabama Polytechnic Institute). From 1935 to 1941, he was a physicist at the Gulf Research and Development Company, Pittsburgh, Pa., where he investigated the dielectric stability of oil and oil-impregnated insulation. The World War II years were spent as research associate and later section supervisor at the California Institute of Technology in rocket development work under an OSRD contract. At the end of the war he joined the newly established Naval Ordnance Test Station as assistant head of the Experimental Operations Department, and in 1947 transferred to the Officer of Naval Research Branch Office, Pasadena. After a two-year tour of duty as Scientific Liaison Officer at the London Branch Office of ONR in 1953–55 and a comparable period in the Western Regional Office of the Office of Ordnance Research, he joined the System Development Corporation, Santa Monica, Calif., in 1958. He is now Assistant to the Director of Advanced Research, Douglas Aircraft Company, Inc., Santa Monica. Since 1958, he has been active in Project Gaslight as a consultant to the Research Projects Laboratory of the Army Ballistic Missile Agency; he has also been a member of the teaching staff of the Mechanical Engineering Department, University of Southern California, Los Angeles, since 1956.

From 1949 to 1953, Dr. Arnquist organized and conducted the series of conferences on military infrared problems, which later became the Infrared Information Symposia (IRIS), and he was a member of Project Metcalf, which studied the Navy's R&D infrared program from 1951 to 1953. He was a member of the Executive Committee of IRIS from 1955 to 1958, and he has attended a number of international scientific conferences including the meeting of the International Consultative Radio Committee in London, 1953, the eleventh general assembly of URSI at The Hague, Netherlands, in 1954, as a member of the U. S. delegation, and in 1959 the fifth meeting and conference of the International Commission for Optics in Stockholm and the Tenth International Astronautical Congress in London.

He is a fellow of the American Physical Society and of the American Association for the Advancement of Science, and a member of Phi Beta Kappa and Sigma Xi. As a result of his war work, he was given the Bureau of Ordnance Technical Award in 1945 and the Joint Army-Navy Appreciation Award for Outstanding Contributions in 1948.

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Helmuth Giessler was born on August 23, 1899, in Berlin, Germany. He entered naval training as a cadet in January, 1917, was discharged at the end of 1918, and re-enlisted in 1923. He was employed on land as communications officer, member of the Naval Electronic Experimental Department, liaison officer to the Signal Corps Commanding Officer of the Luftwaffe, and as chief of the development section for communications in the High Command. At sea, he served a Officer of the Watch on capital ships (battleships) and as radio officer on cruisers sailing abroad. He was navigation officer on the battleship *Scharnhorst* until 1942, when he became the Executive (First) Officer. In 1944, as a captain, he became commander of the cruiser *Nürnberg*, remaining in that post until the end of the war and transference of the ship to the USSR. He then served as chief of the Marine Technical Unit of the U. S. Navy in Bremerhaven, until 1948, when he went into business. Since 1954, he has been with the German Institute of Navigation in Düsseldorf.

H. Giessler

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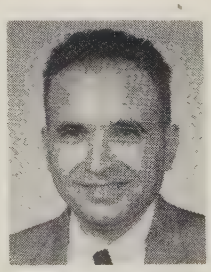
Morris Halio (A'54–M'49–SM'59) was born on February 28, 1912, in New York, N. Y. He received the B.S. degree in physics from the College of the City of New York, N. Y. Postgraduate work was done in mathematics, physics, engineering, electronics, radio and television at the following institutions: Brooklyn Polytechnic Institute, Brooklyn, N. Y.; Howard University, Washington, D. C.; Johns Hopkins University, Baltimore, Md.; and the University of Delaware, Newark, Del.



M. Halio

From June, 1940–November, 1943, he was a physicist at the U. S. Naval Engineering Experiment Station, Annapolis, Md. From November, 1943, to August, 1944, he was employed as a radio engineer for Bendix Radio, Baltimore. In August, 1944, he became a radio instructor at the Holabird Signal Depot, Baltimore. In September, 1945, he left to join the Ballistic Research Laboratories, Aberdeen Proving Ground, Md., as an electronic scientist.

From April, 1959, to July, 1960, he served as Chief Operations Research Analyst for the F-106 Joint Test Force, Air Defense command, U. S. Air Force, at McGuire AFB, N. J. Since July, 1960, he has been with the Plans and Programs Office of Headquarters, U. S. Army Transportation Materiel Command, in St. Louis, Mo., in the capacity of Chief Operations Research Analyst.

Mr. Halio is a member of the Operations Research Society of America, the American Ordnance Association, and the Army Aviation Association of America. He represented the U. S. Army on the Engineering Panel of the Naval Bureau of Ordnance VT (Electronic) Fuse Committee.

Henry Magnuski (A'40–SM'46) was born in Warsaw, Poland, on January 30, 1909. He received the diploma in electrical engineering (equivalent to an M.S. degree) in 1934 from the Technical University of Warsaw. He was a senior engineer in Polish State Radio and Telephone Works before coming to the United States in 1939.

H. Magnuski

Mr. Magnuski joined Motorola, Inc., Chicago, Ill., in 1940, and was engaged in the design of FM Communication Equipment including the development of the Walkie-Talkie (SCR-300). Later, he was responsible for the design and production of the AN/CPN-6 Microwave Radar Beacon for which he was awarded the U. S. Navy Certificate of Commendation.

After the war, he initiated and developed a full line of Motorola Microwave Relay equipment for multichannel telephone, radar data, and TV video transmission. He is a consultant for Two-Way Communication, Microwave and Military Equipment Systems. One of his latest contributions is the development of the Single Sideband Radio Central Concept, AN/MRC-66. His present position is that of Associate Director of Research, Military Division.

Mr. Magnuski is a member of AIEE.

David D. Woodbridge was born in Seattle, Wash., on January 29, 1922. He received the B.S. degree from the University of Washington, Seattle, in 1949, and was on the staff of Massachusetts Institute of Technology, Cambridge, in the Meteorology Department during 1949 and 1950. He received the M.S. and Ph.D. degrees in physics from Oregon, State College, Corvalis, in 1951 and 1956, respectively.

D. D. Woodbridge

From 1954 to 1957 he was Professor of Physics at the Colorado School of Mines, Golden. In 1957 he joined the Army Ballistic Missile Agency in Huntsville, Ala., as Assistant Chief of the Physics and Astrophysics Branch of the Research Projects Laboratory. He later became Chief of the Space Environmental Branch of the Laboratory. At the present time, he is Assistant Director of the Research and Engineering Staff of the Army Rocket and Guided Missile Agency.

Dr. Woodbridge is a member of Sigma Pi Sigma and Pi Mu Epsilon, and an associate member of Sigma Xi.

INFORMATION FOR AUTHORS

The PGMIL TRANSACTIONS is intended to bridge the gap between the various disciplines contributing to military electronics. Since this includes most of the branches of electronics, of the military services, and of the many fields which are associated with but not actually within the realm of electronics, it is essential that the papers published be of broad interest. The emphasis should be on readable, thought-provoking material that stimulates an attitude of open-mindedness and curiosity.

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Suggestions are earnestly solicited from the membership on topics for future issues of the PGMIL TRANSACTIONS. Suggested topics should be sent to the PGMIL TRANSACTIONS Editor, Donald R. Rhodes, Radiation Incorporated, P.O. Box 6904, Orlando, Fla.

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Publication Date	*Topic*	*Guest Editor*	*Manuscript Deadline*
July, 1961	"Micro Electronics and Systems" Solid-state circuit techniques and their influence on future system design.	Dr. J. E. Thomas, Jr. Director of Research and Engrg. Semiconductor Division Sylvania Electric Products, Inc. Woburn, Mass.	April 1, 1961
October, 1961	"Missile and Space Range Instrumentation" Radar, optics, telemetry, timing, intrarange communications, frequency coordination, trajectory computation, etc.	Mr. A. G. Waggoner Asst. Director of Defense Research and Engrg. The Pentagon Washington 25, D. C.	July 1, 1961
	Next Issue		
April, 1961	"Advanced Radar Techniques"	Mr. J. M. Bridges Director of Electronics Office Director, Defense Research and Engrg. The Pentagon Washington 25, D. C.	

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